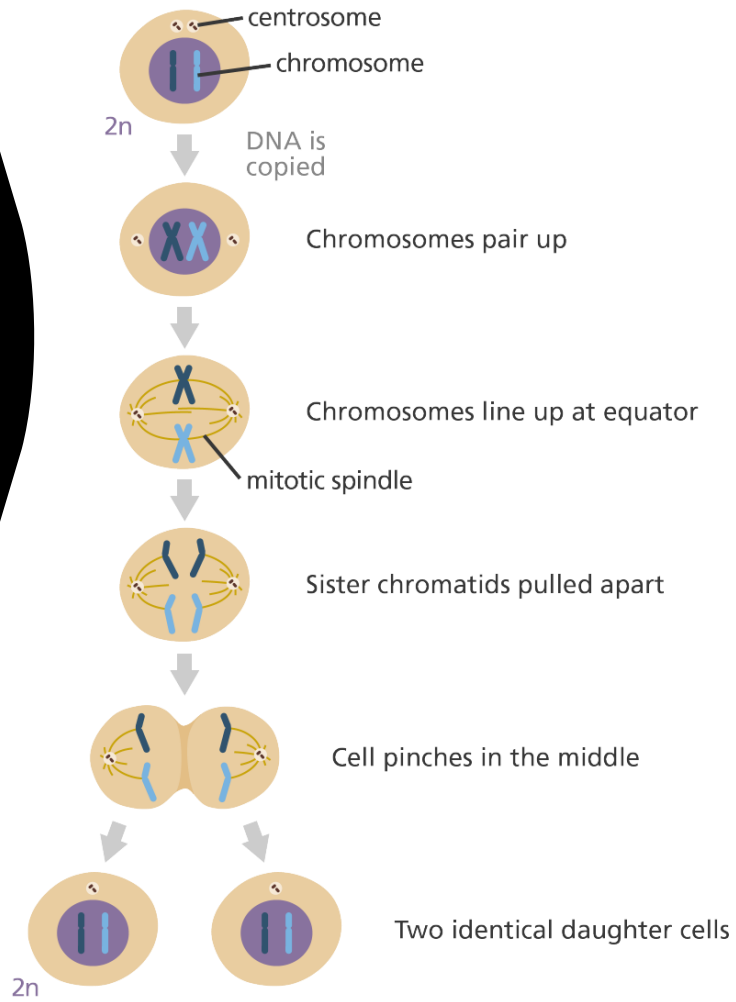
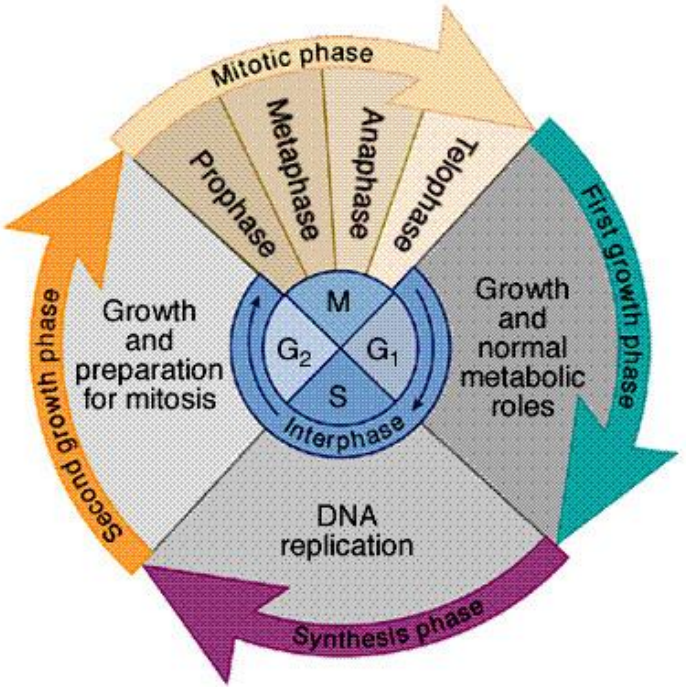
Cambridge Assessment International Education

AS Level
Chapter 5

The Mitotic Cell Cycle



Chapter Outline



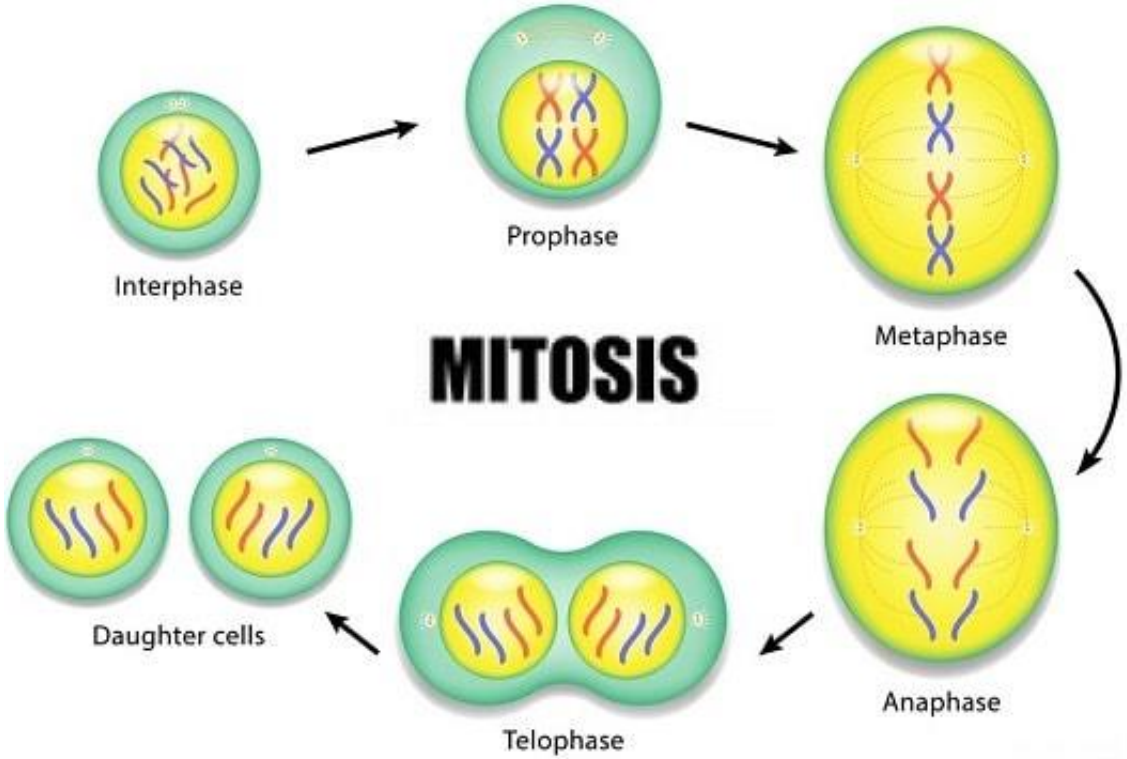
Part 1: Cell Division

- Structure of chromosomes
- Importance of mitosis
- Interphase
- **Mitosis**
- Cytokinesis

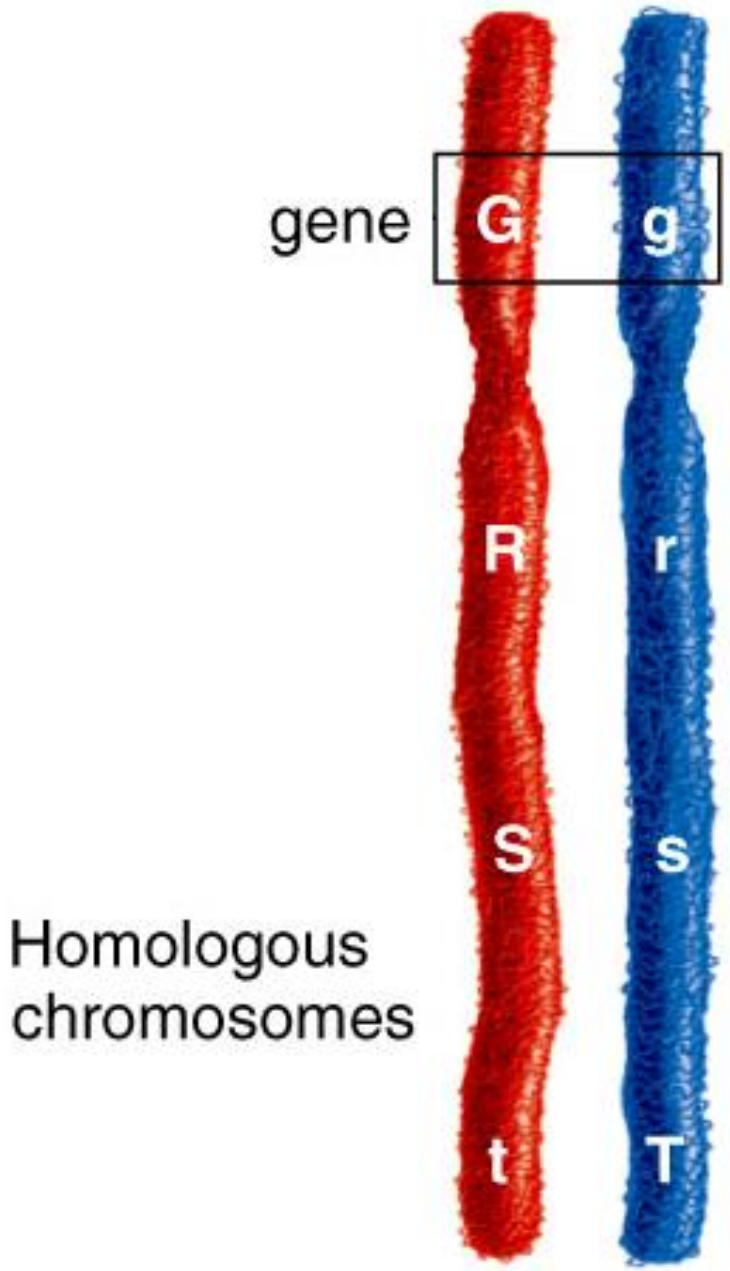
Part 2: Regulation of the Cell Cycle

- Importance of **telomeres**
- **Stem cells** in cell replacement and tissue repair
- **Cancer and tumour** formation

Part 1: Cell Division



Terminology



DNA Packaging

- Double-helix **DNA** is associated with **histone** proteins

- DNA wraps and coils around histone proteins

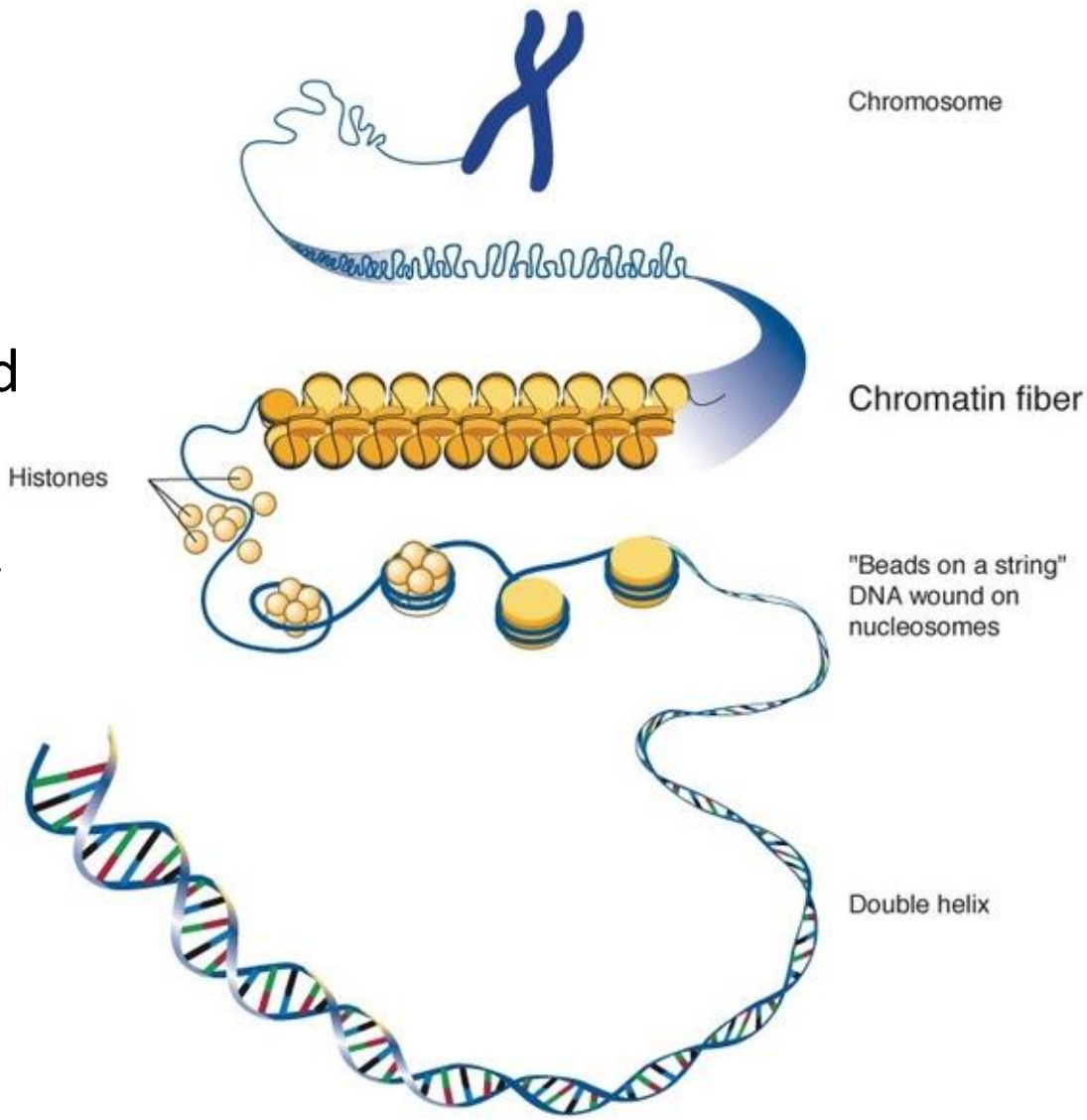
→ Forms **chromatin**

→ Found in this form usually

During cell division,

- DNA undergoes further coiling

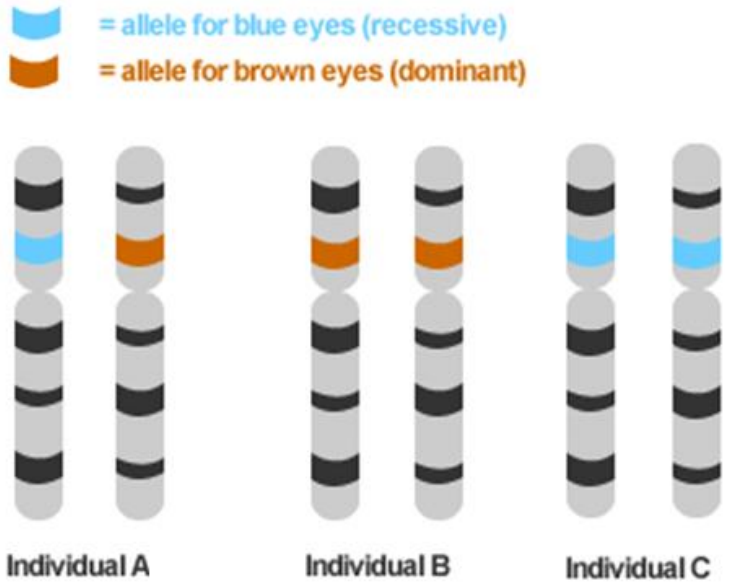
→Form tightly-coiled DNA = **chromosomes**



https://www.dnalc.org/resources/3d/07-how-dna-is-packaged-basic.html

Structure of Chromosomes

- 1 chromosome has several thousand genes
- **Genes** = DNA that codes for protein
- **Locus** (plural: loci) = Position of gene in a chromosome



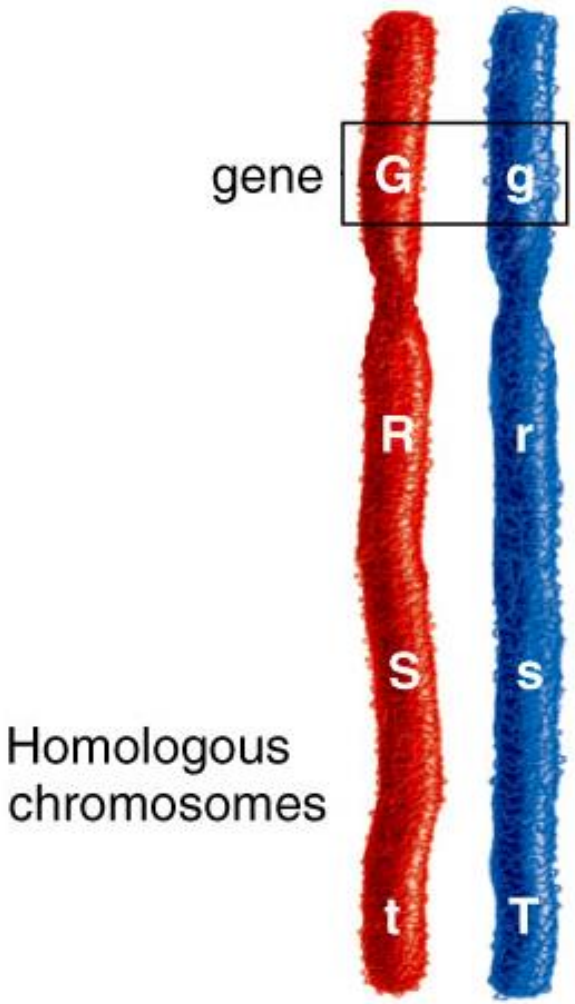
- If same species, genes are on same chromosome and loci

→ But different alleles

- **Alleles** = **Different forms of one gene**
- Can be **dominant** or **recessive**
- E.g. Gene - Eye colour

  Alleles - Allele for blue eyes, allele for brown eyes etc.

Homologous Chromosomes



- **Pairs of chromosomes** found in diploid cells
- 1 maternal and 1 paternal

- Similar centromere's position
- Similar chromosome's size and shape
- Same genes, different alleles

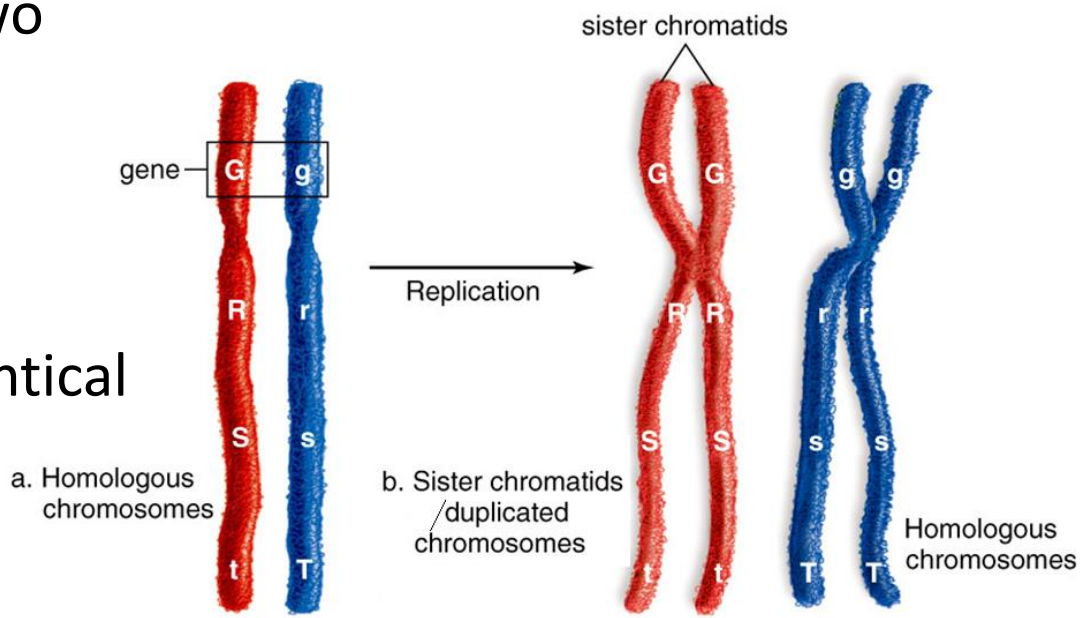
Sister Chromatids – Duplicated DNA

- During **interphase**, **DNA replication** occurs in the nucleus
- One chromatid becomes two
- Two identical chromatids

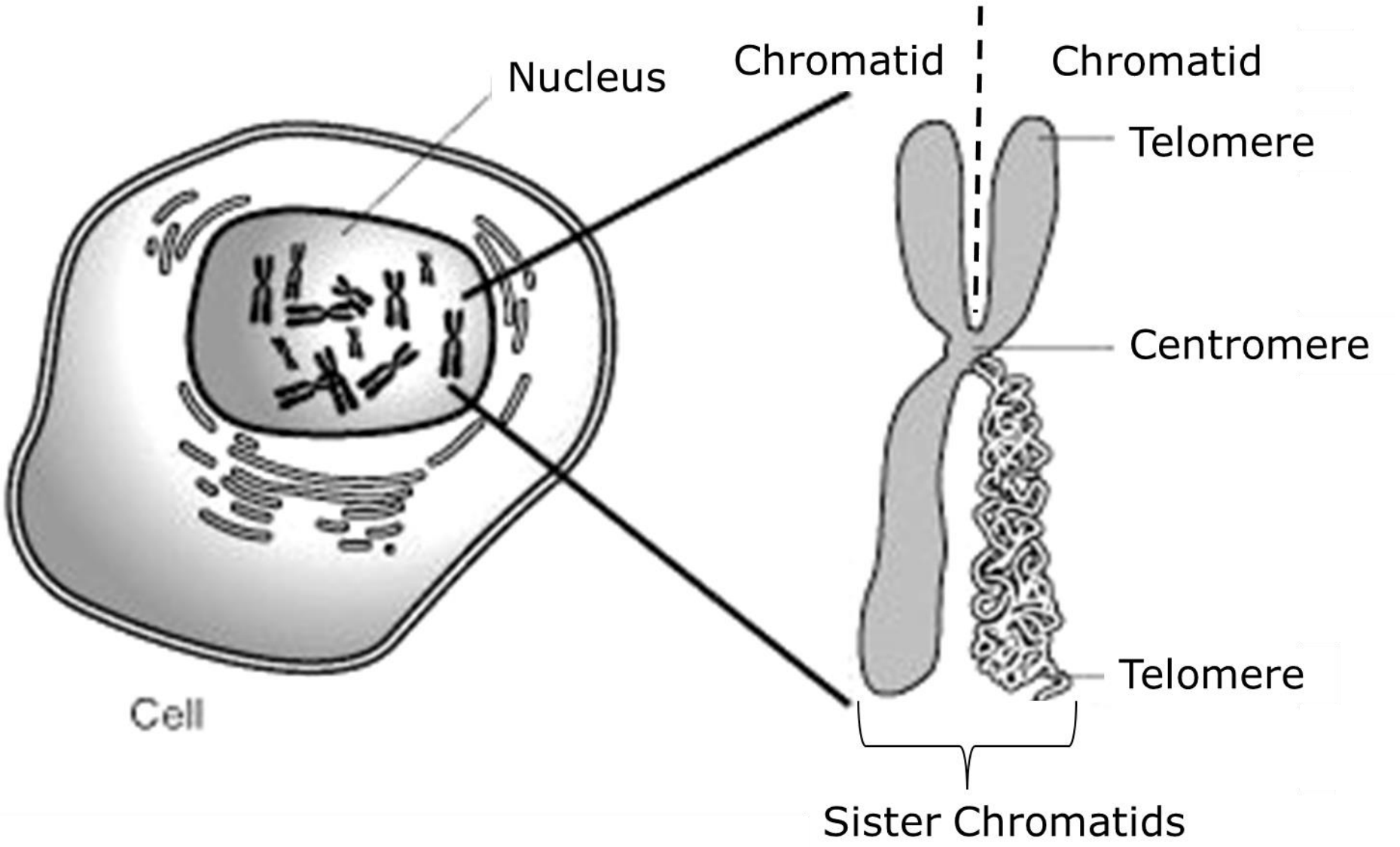
= **Sister chromatids**

- Sister chromatids have identical copies of genes

- **Centromere** holds two chromatids together

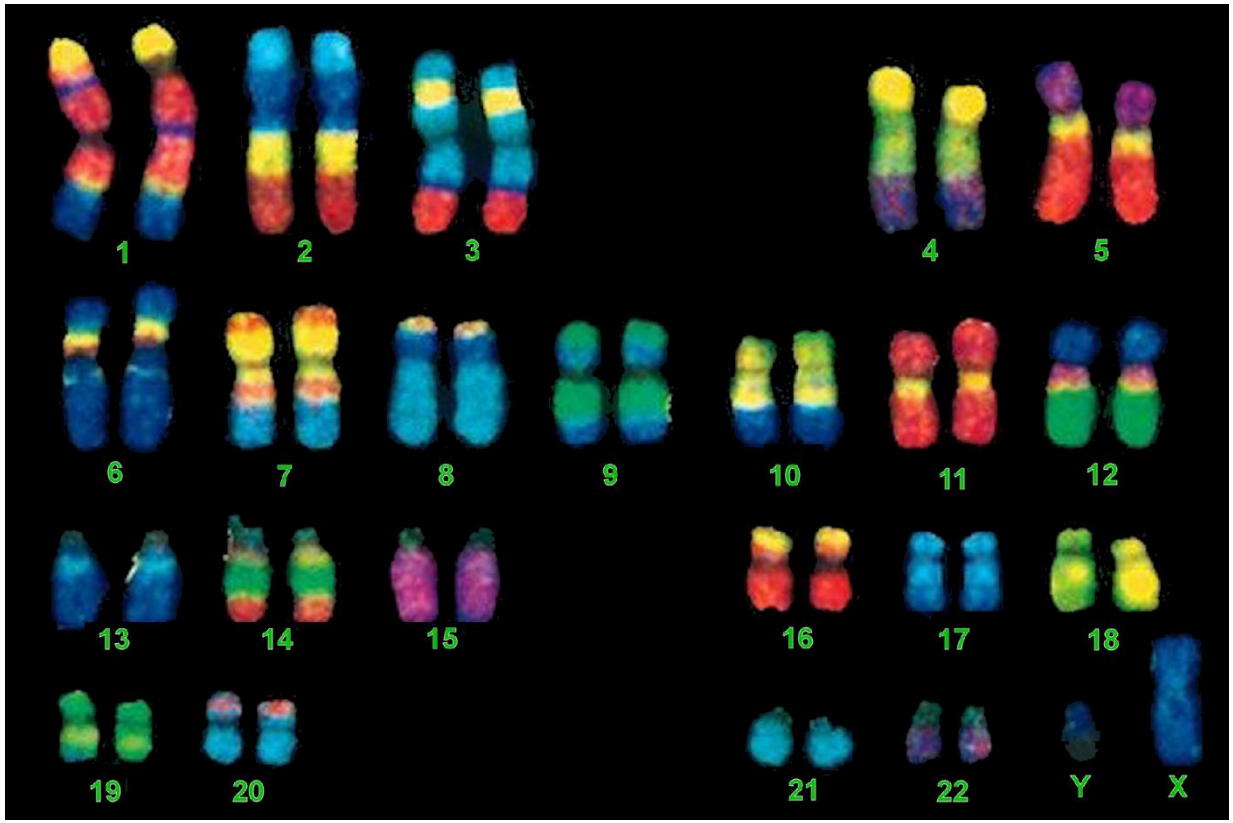


Structure of Chromosomes



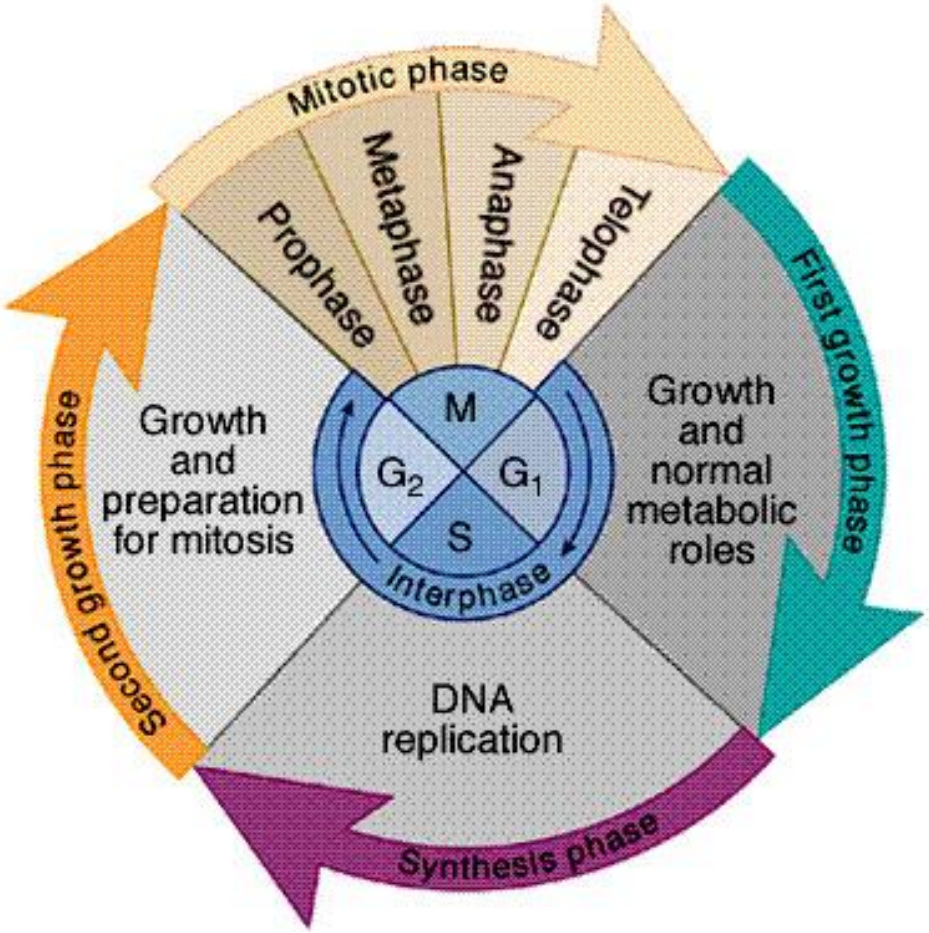
Karyogram

- Total set of chromosomes in an organism
- Arranged in order of size
- No. of chromosomes are specific to each species
- Human diploid cells have **23 sets** of chromosomes (**2n = 46**)



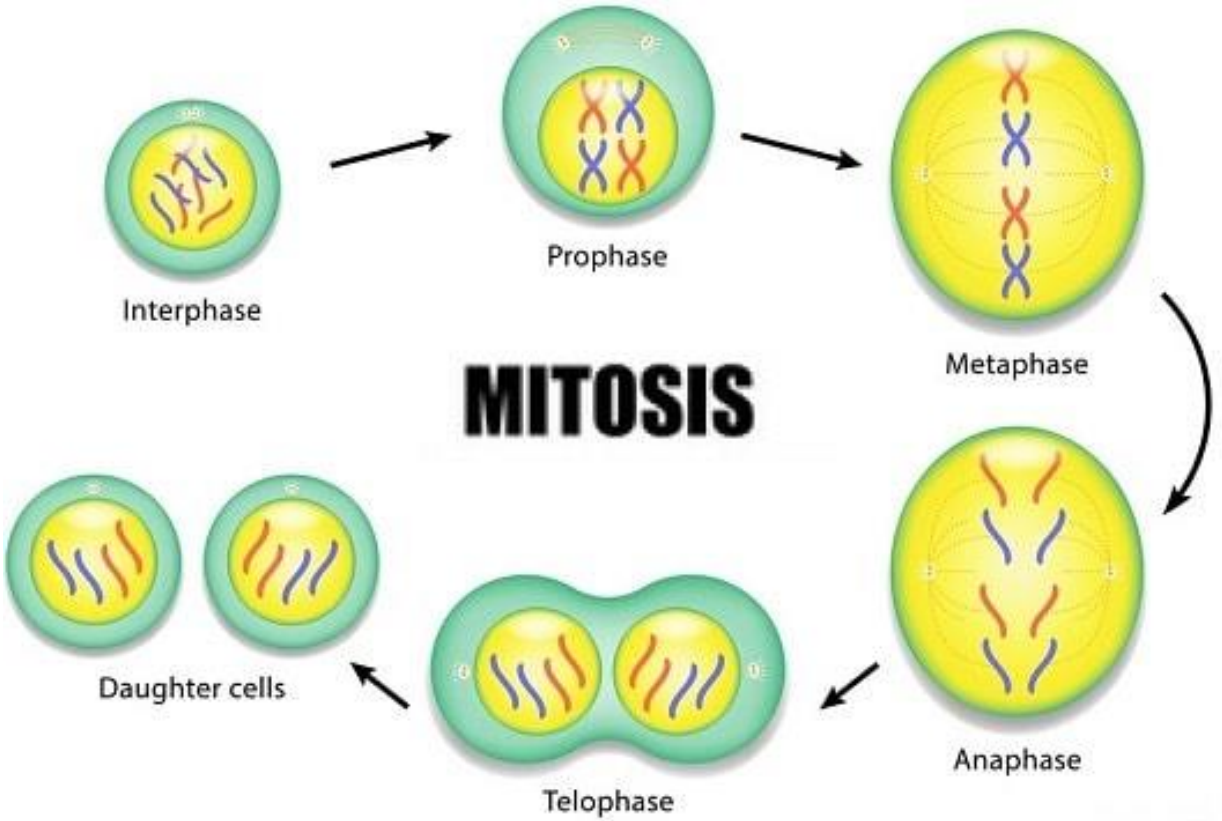
2 types of chromosomes: **Sex chromosomes** and **autosomes**

Mitosis


Mitotic phase
Prophase
Metaphase
Anaphase
Telophase
First growth phase
Growth and normal metabolic roles
DNA replication
Synthesis phase
Second growth phase
Growth and preparation for mitosis
M
G2
G1
S
Interphase

Introduction to Cell Division

- All cells in our body are **genetically identical** (except gametes)
- Cells reproduce / divide
- To pass copies of genes to daughter cells



Diploid vs Haploid cells

Diploid cells have two complete sets of chromosomes (2n)

- 1 maternal, 1 paternal
- Somatic cells = all cells except for gametes / germ cells
- In humans: **2n = 46**

→ Result of **mitosis**

Haploid cells have only one set of chromosomes (n)

- Gametes / germ cells
- In humans: **n = 23**

→ Result of **meiosis** (aka reduction division)

Importance of Mitosis

- Results in **two genetically identical** daughter cells

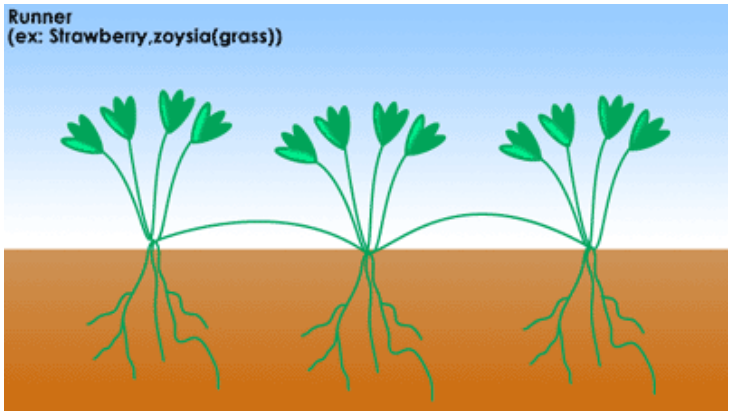
→Same number of chromosomes as parent cell

Biological importance:

1) **Maintaining number** of chromosomes

→Ensuring genetic stability /

→New cells can retain function



2) **Growth** of multicellular organisms

3) **Cell replacement / Tissue repair**

4) **Asexual reproduction**
E.g. vegetative reproduction in plants / cloning

The Mitotic Cell Cycle

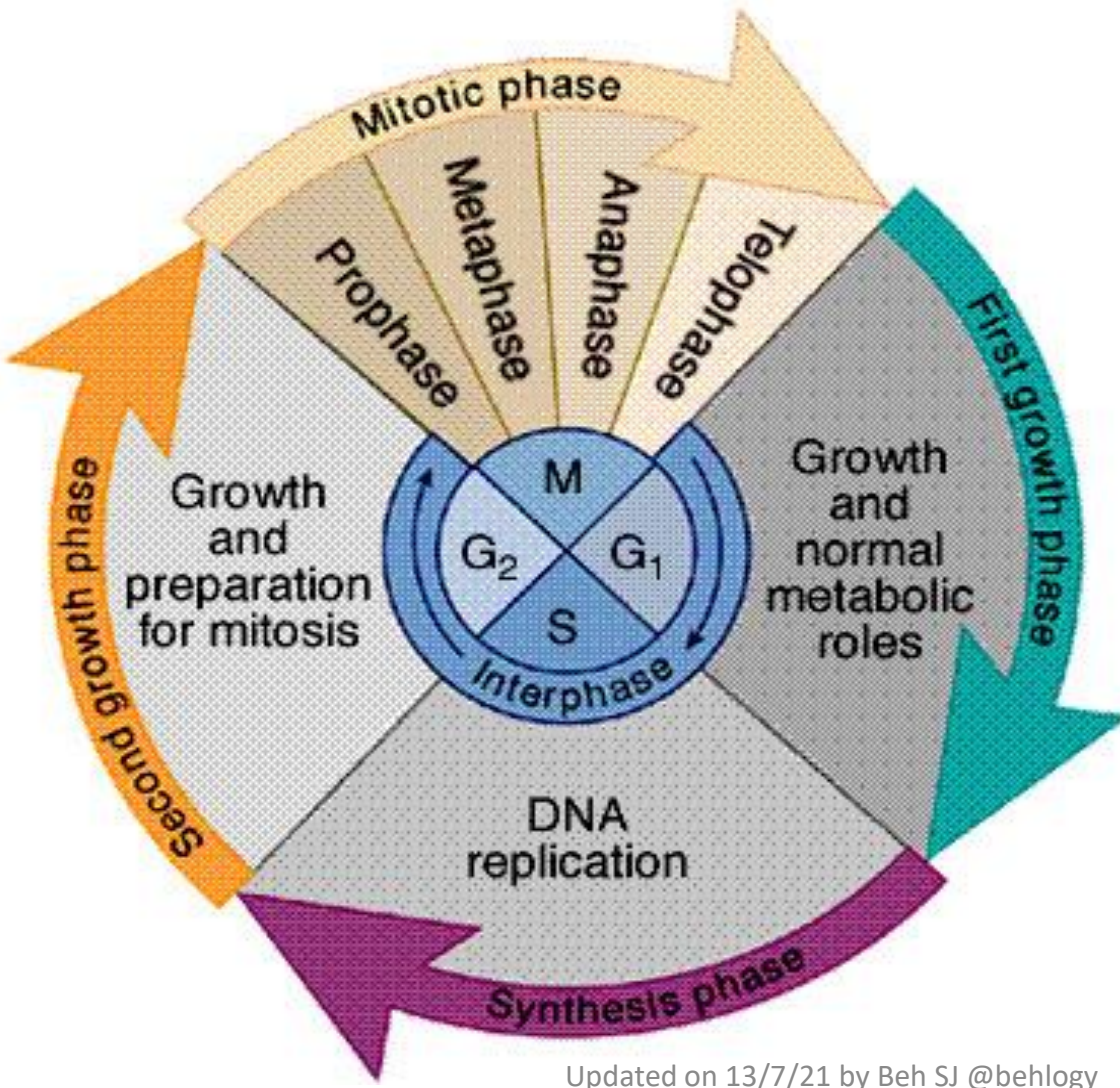
1) Interphase

- G_1
- S
- G_2

2) M phase (mitosis)

- Prophase
- Metaphase
- Anaphase
- Telophase

3) Cytokinesis



Cell Cycle and Mitosis [3D Animation]
https://www.youtube.com/watch?v=xsrH050wnIA

Interphase

1) G_1 phase

- **Growth** of cell
- Synthesis of proteins and other substances

2) S phase

- **DNA Replication**

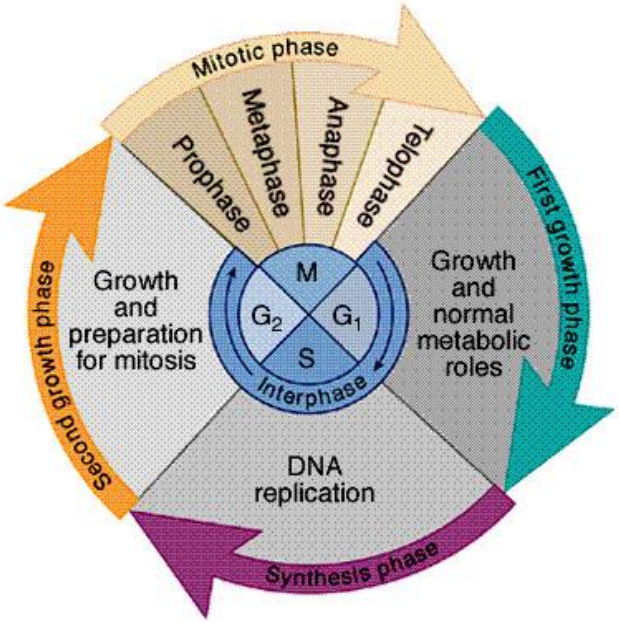
→ Result in sister chromatids

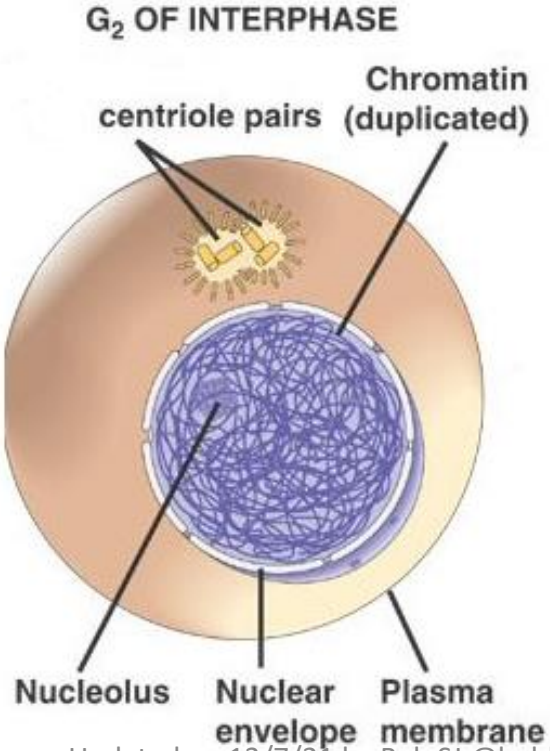
3) G_2 phase

- **Growth**
- **Duplication of centrioles**

→ Form 2 pairs of centrosomes

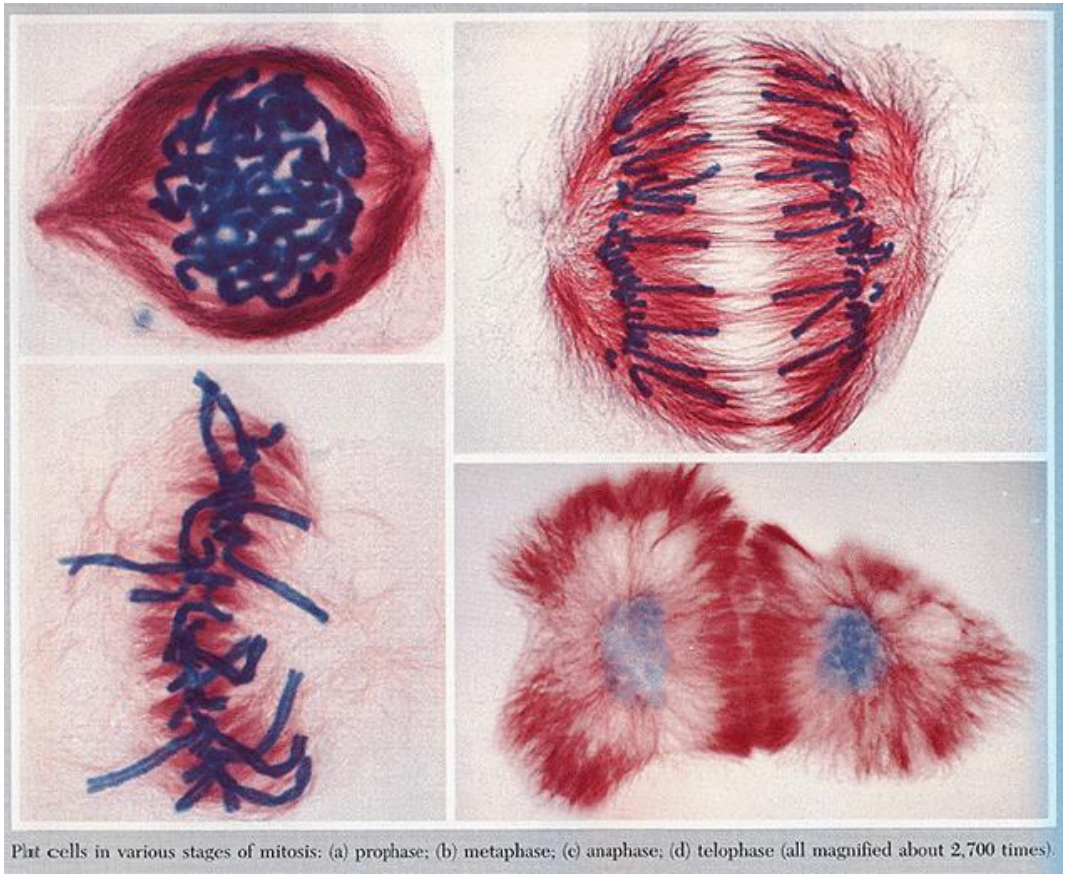
- **Repair** of DNA replication errors





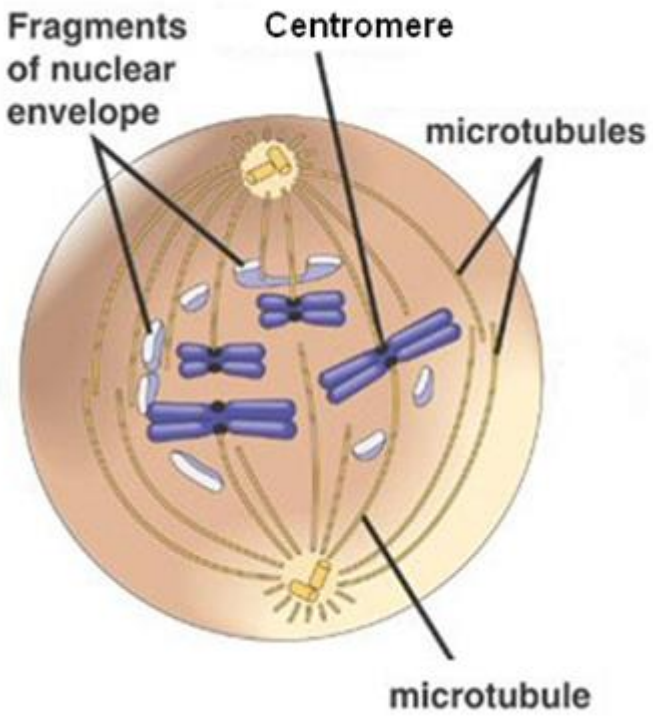
Mitosis

- Prophase
- Metaphase
- Anaphase
- Telophase



Plant cells in various stages of mitosis: (a) prophase; (b) metaphase; (c) anaphase; (d) telophase (all magnified about 2,700 times).

Prophase



- **Condensation** of chromatin

→ Become shorter and thicker

→ Appearance of chromosomes

→Visible as two, sister chromatids

- **Spindle fibres** form

→ Start attaching to centromere

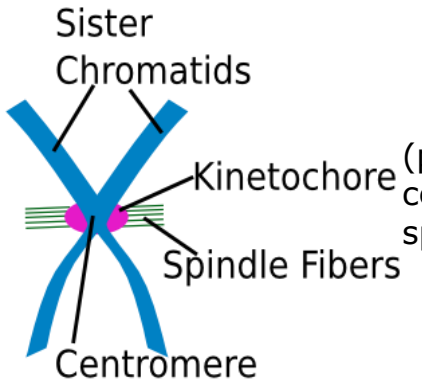
- Centrosomes move to opposite poles
- Nuclear envelope breaks down
- Nucleolus breaks down

Metaphase

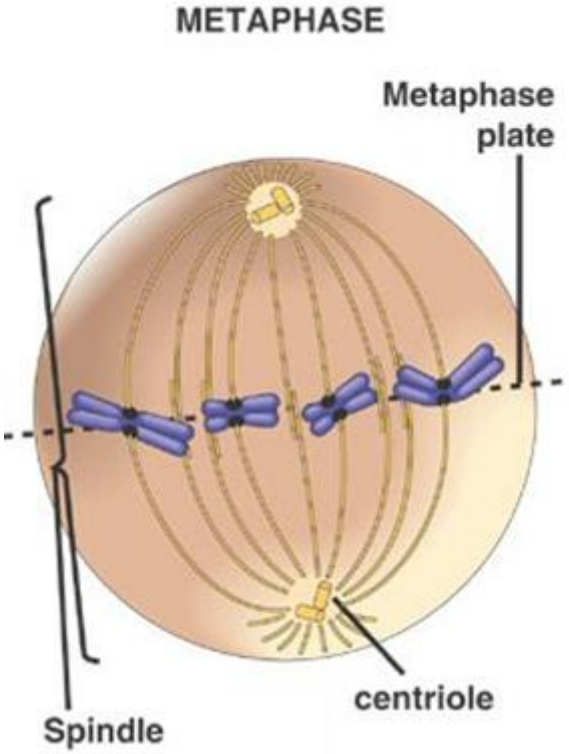
- Centrosomes reach opposite poles
- Spindle fibres are fully formed

- Chromosomes line up at the **metaphase plate** / equator

- Chromosomes **attached to spindle fibres at centromere** / kinetochore



(protein structure at centromere where spindle attach to)



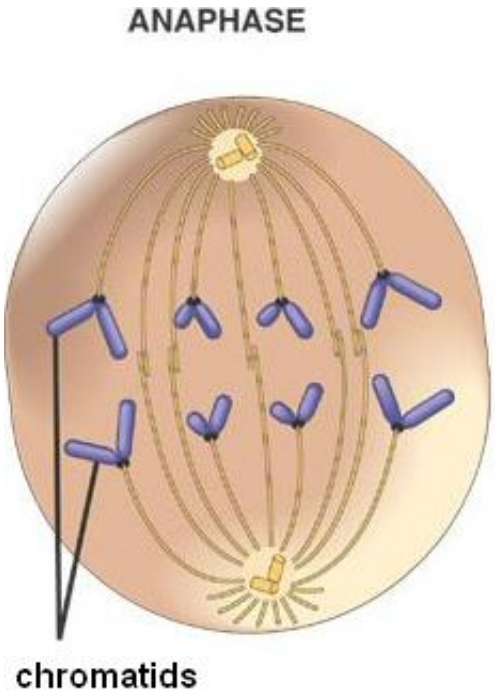
Anaphase

- **Centromere** of each chromosome **divides**
- Sister chromatids split at the centromere

- Spindle microtubules **shorten**

- **Chromatids pulled to opposite poles**

→ with **centromeres leading** towards poles



Telophase

- Chromatids reach the poles

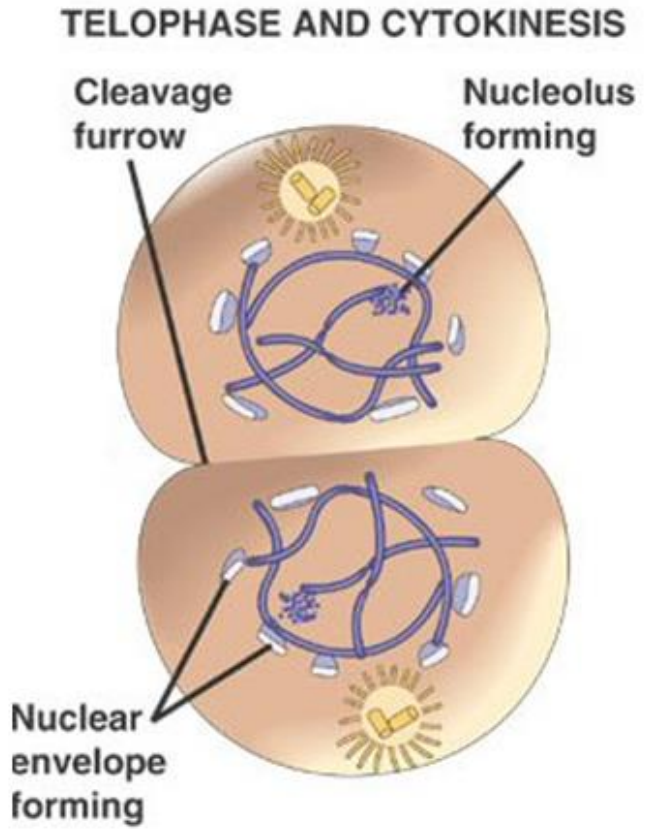
- **Chromosomes decondense**

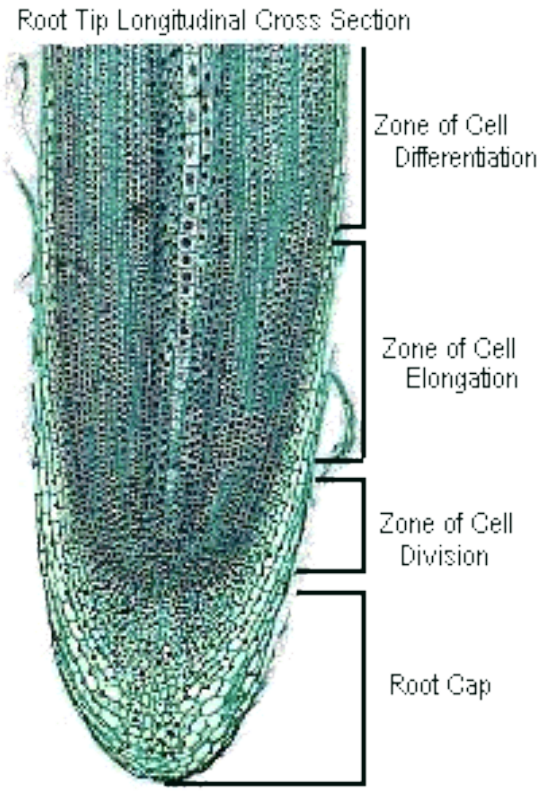
→ Become long and thin

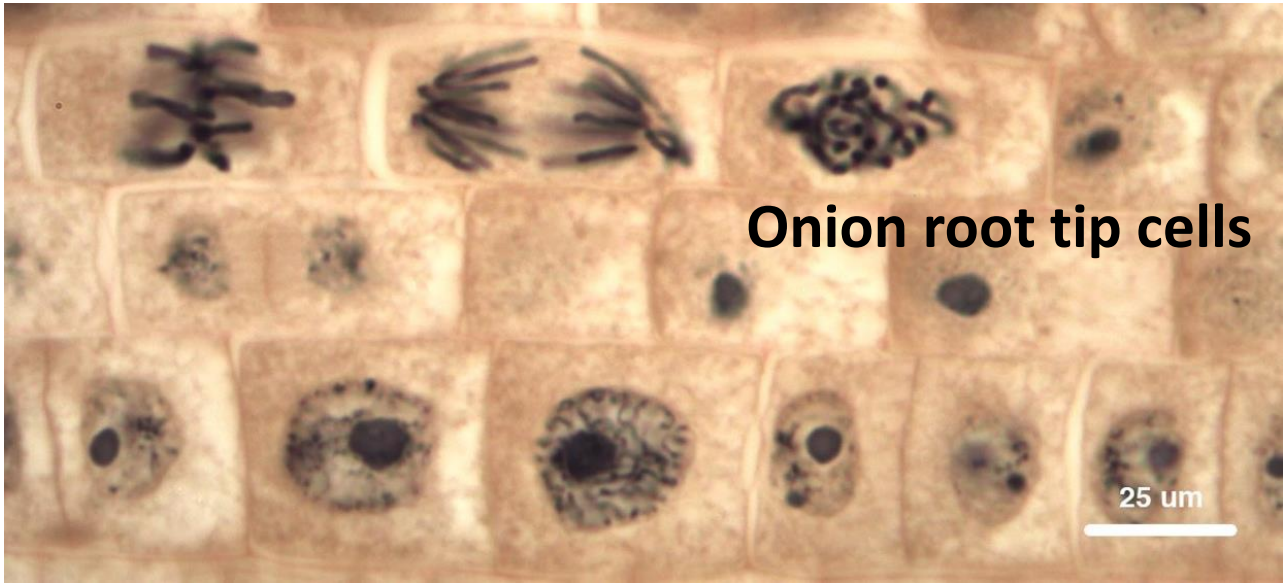
- **Nucleolus** reforms
- **Nuclear envelope** reassembles

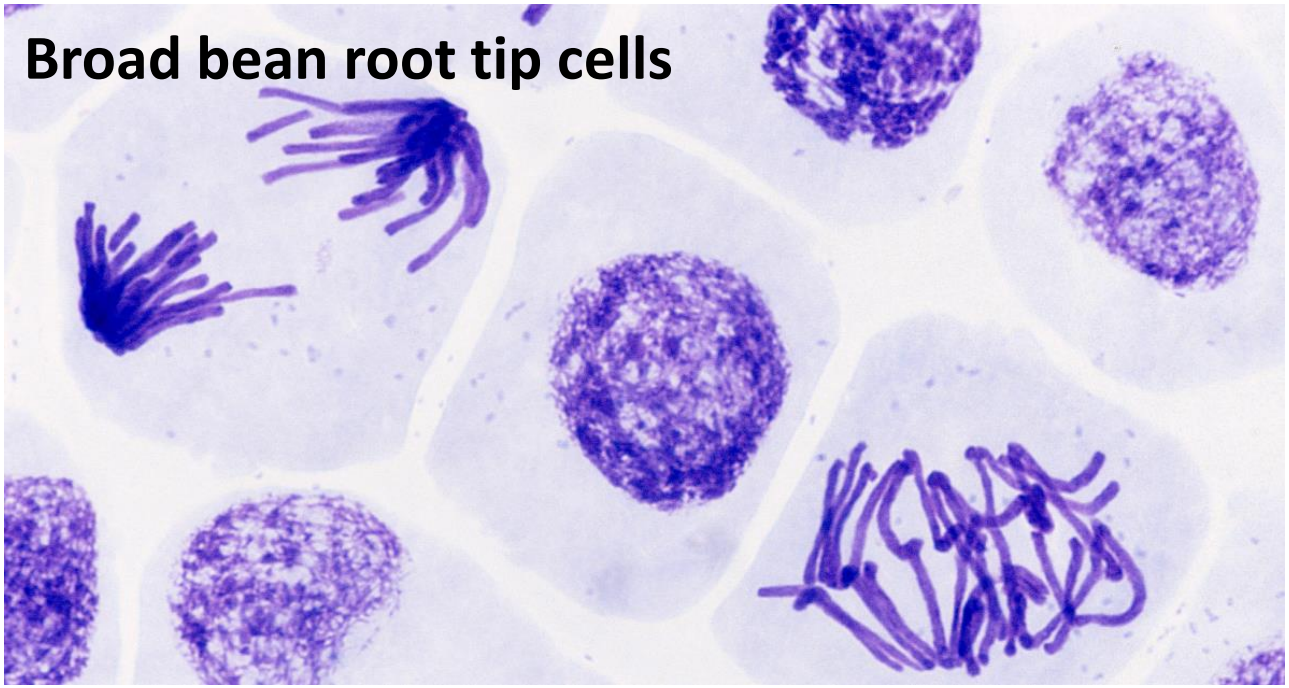
- Spindle fibres breaks down

- Cytokinesis starts




Root Tip Longitudinal Cross Section
Zone of Cell Differentiation
Zone of Cell Elongation
Zone of Cell Division
Root Cap


Onion root tip cells
25 um


Broad bean root tip cells

Cytokinesis

- Division of the cell's cytoplasm

In animal cells:

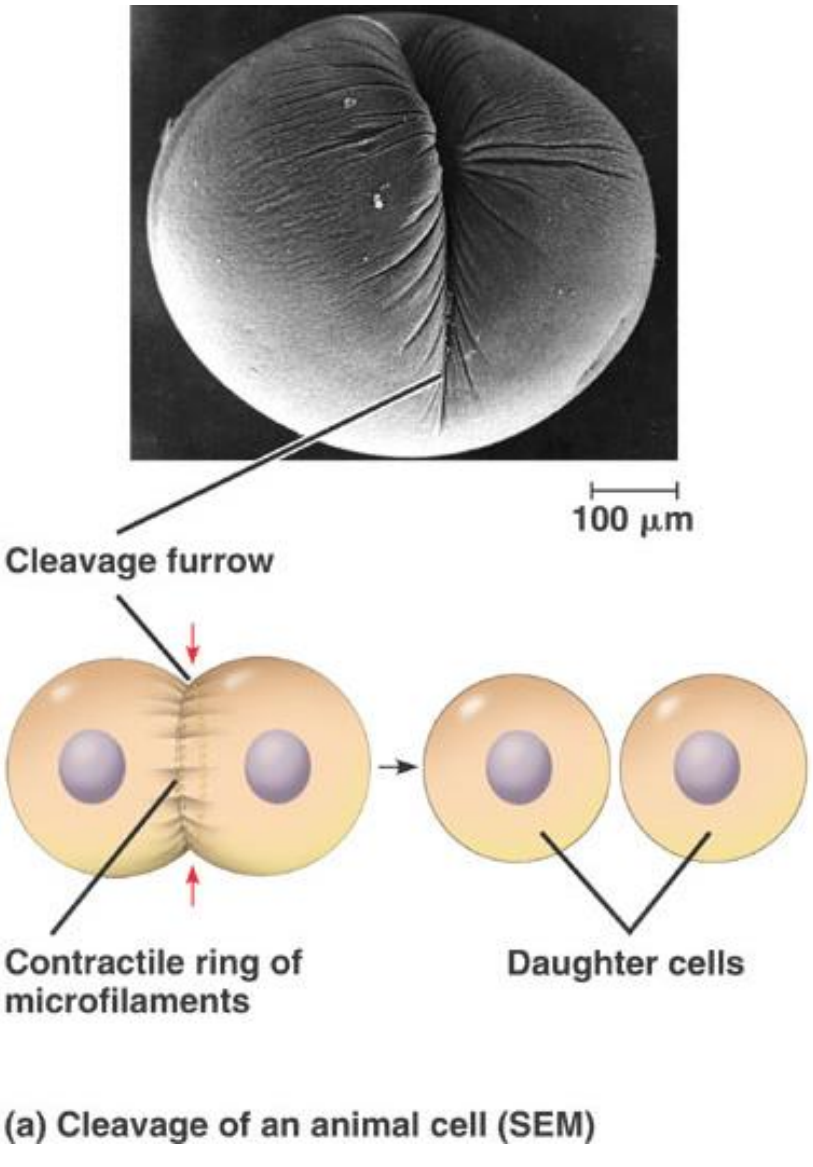
- **Cell membrane drawn together**

→ By contractile ring of microfilaments

→ Forms a **cleavage furrow**

→ Creating a drawstring effect

- **Cell membrane fuses**
- To divide cell into two
- Organelles are shared out



Cytokinesis

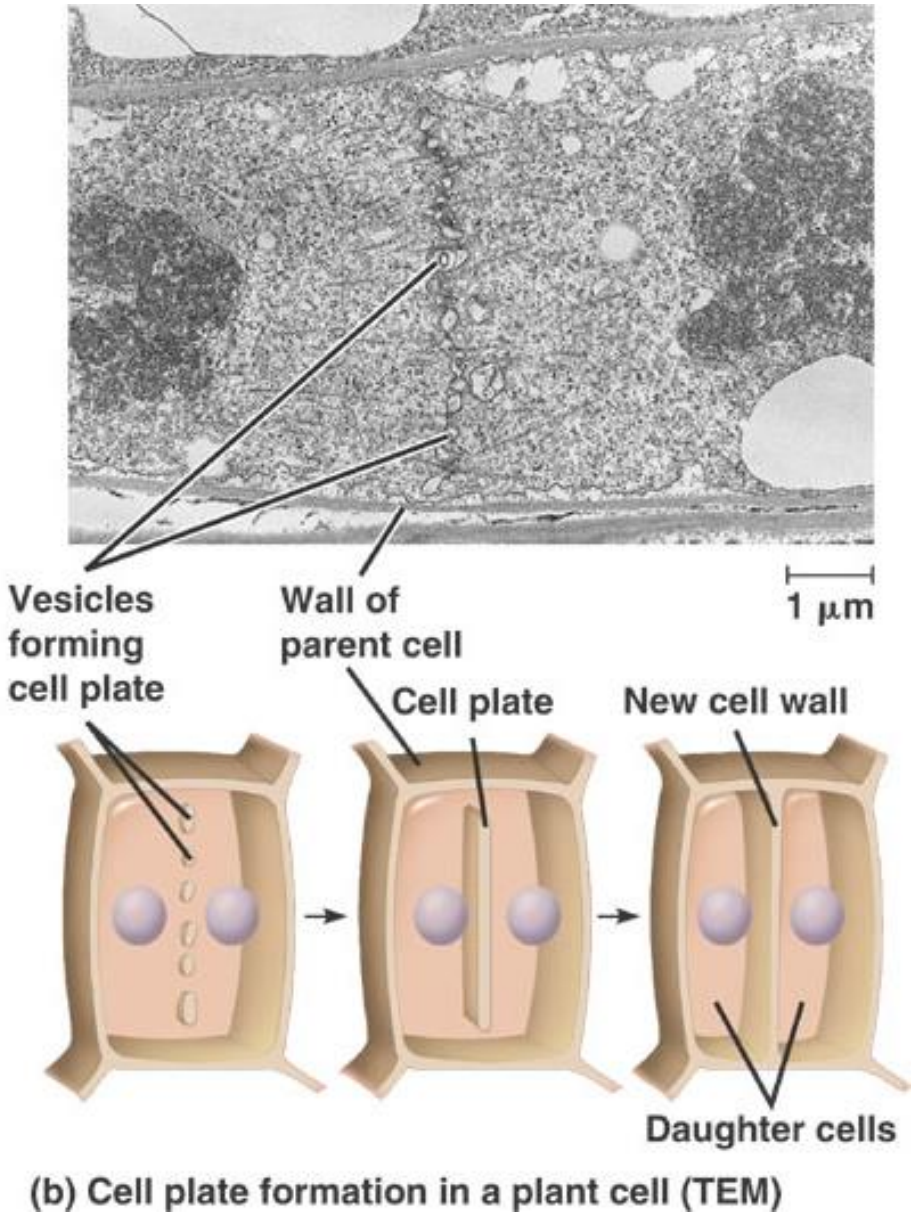
In plants:

- **Vesicles** transported to equator

→ To form **cell plate** at equator

- **Cell wall** laid down

- So cytoplasm divided into two
- Organelles are shared out

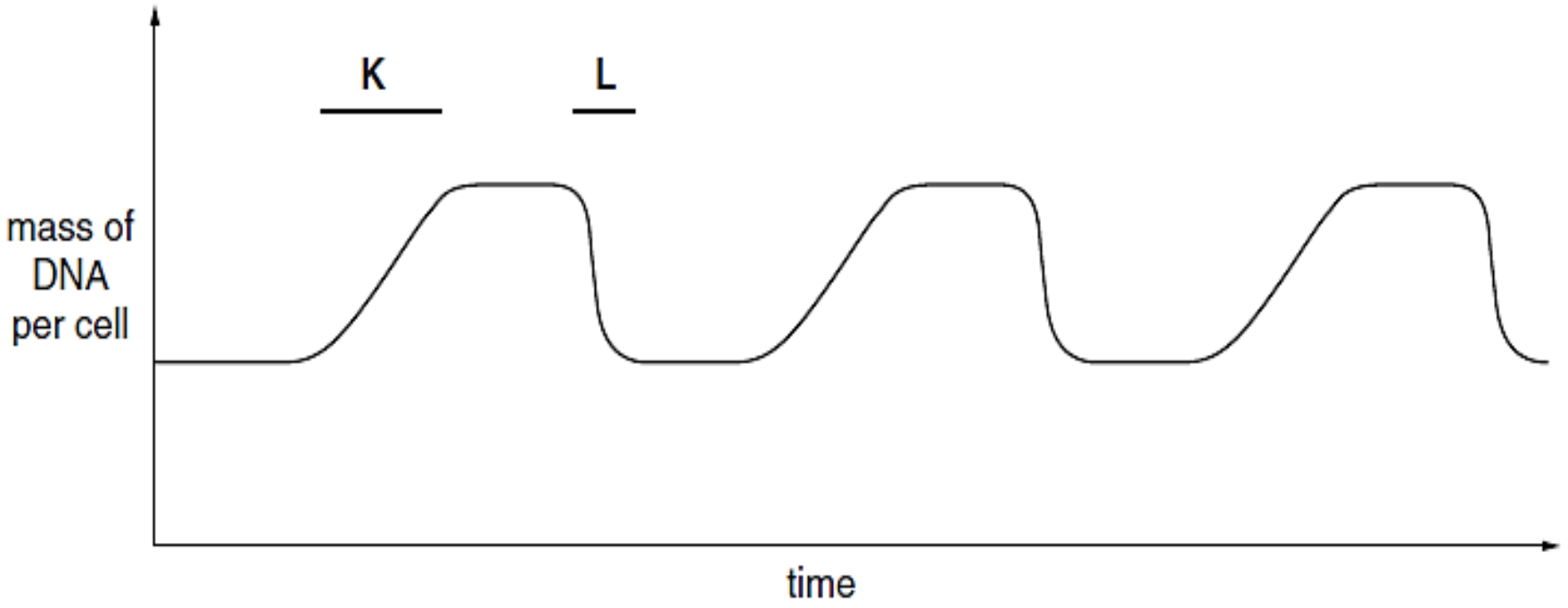


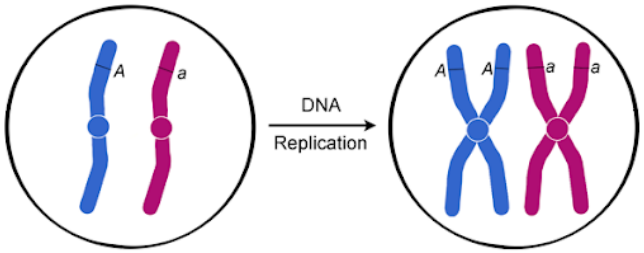
(b) Cell plate formation in a plant cell (TEM)

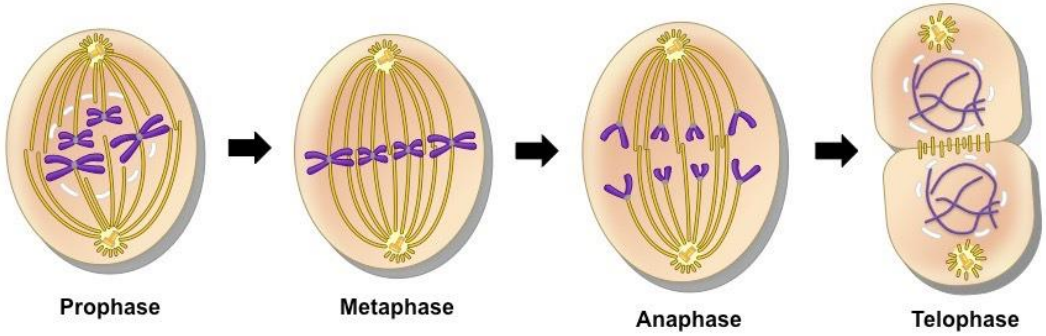
Which row is correct for a human cell just before the cell enters prophase of mitosis?

	number of chromatids	number of molecules of DNA in nucleus	spindle present	nuclear envelope present
A	46	46	yes	no
B	46	92	yes	yes
C	92	46	no	yes
D	92	92	no	yes

Name process K and L.

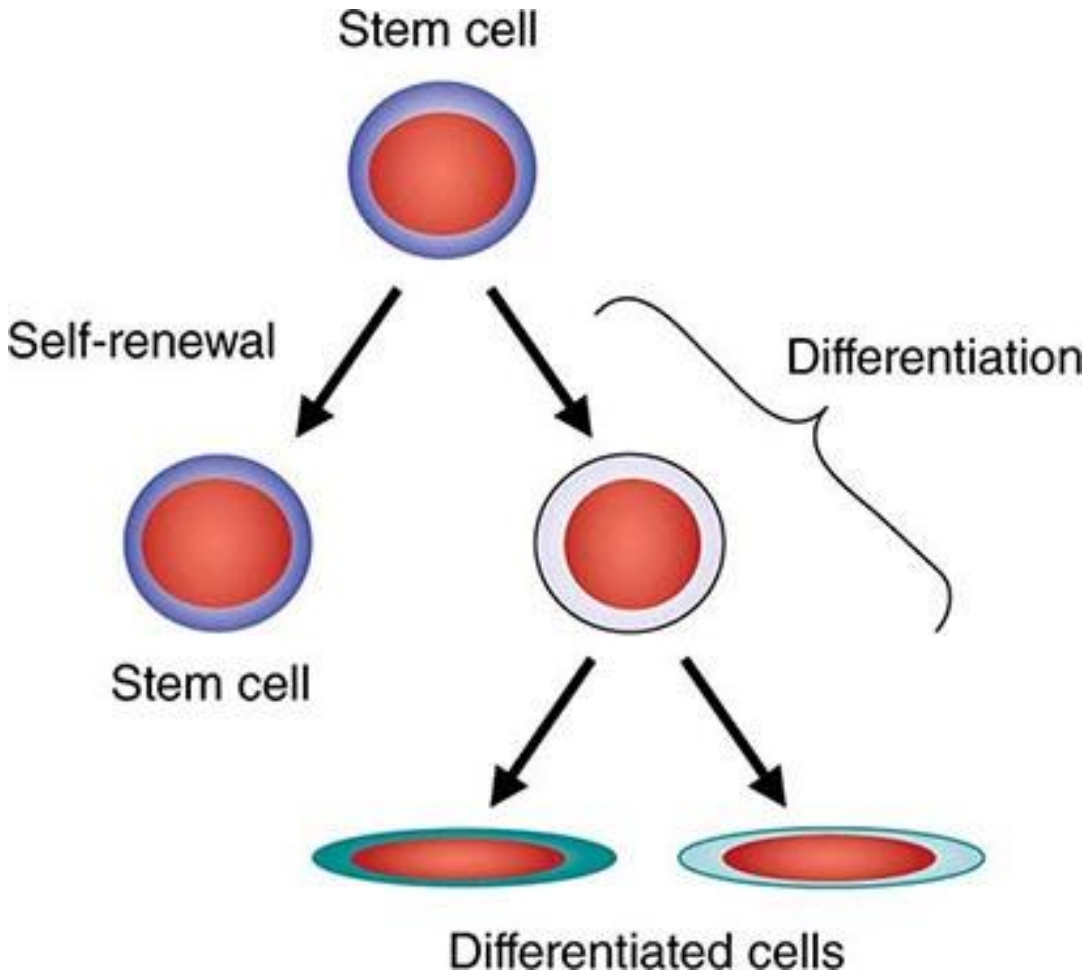






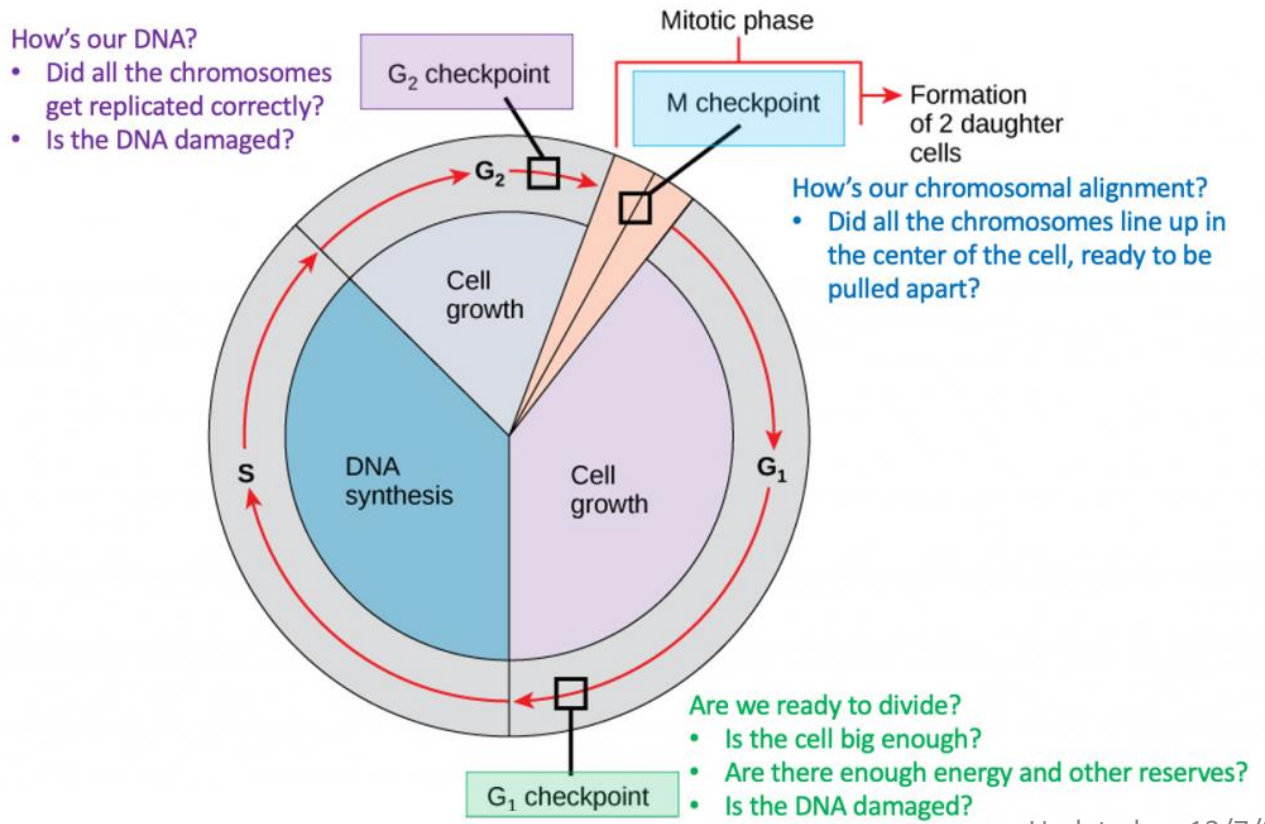
Phase	G1	S	G2	P	M	A	T + C	G1
Number of chromosomes	46	46	46	46	46	92	92	46
Number of chromatids / Number of DNA molecules	46	92	92	92	92	92	92	46
Amount of DNA / Mass of DNA	x 1	x 2	x 2	x 2	x 2	x 2	x 2	x 1

Part 2: Regulation of the Cell Cycle

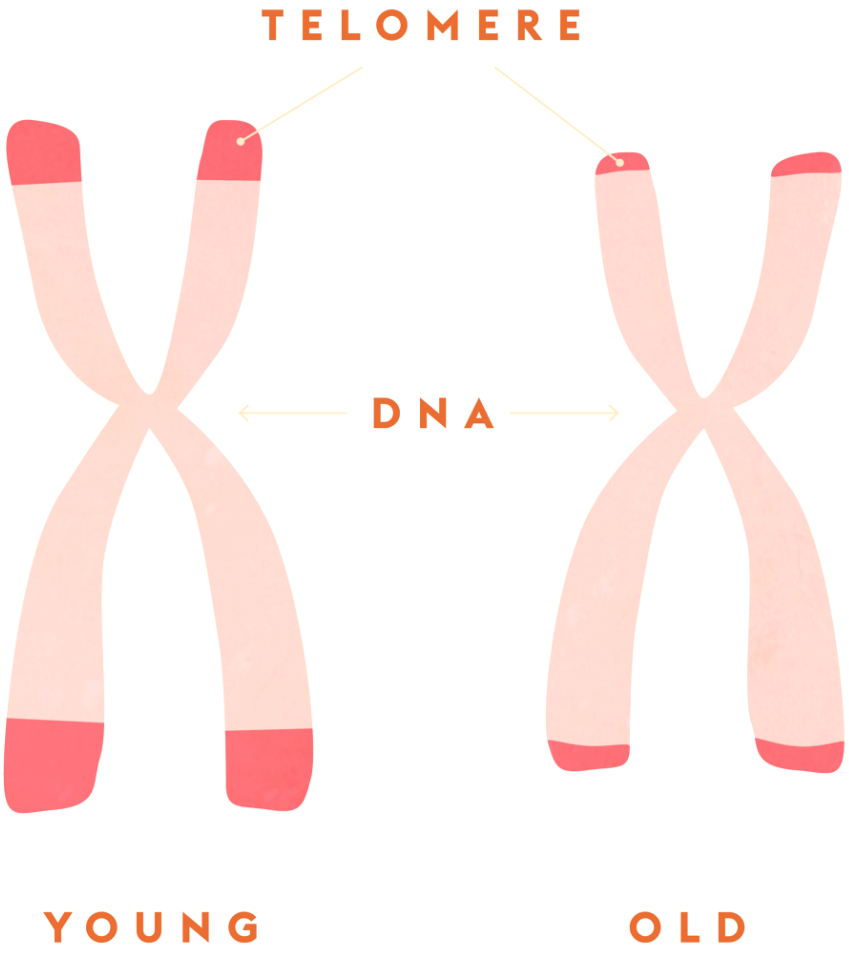


Checkpoints

- The duration of the cell cycle differs for diff types of cells
- The cell cycle is tightly controlled and coordinated
- **Checkpoints** prevent the cycle from continuing when mistakes are made or DNA is damaged


How's our DNA?
• Did all the chromosomes get replicated correctly?
• Is the DNA damaged?
G2 checkpoint
Mitotic phase
M checkpoint
Formation of 2 daughter cells
How's our chromosomal alignment?
• Did all the chromosomes line up in the center of the cell, ready to be pulled apart?
G2
Cell growth
S
DNA synthesis
Cell growth
G1
Are we ready to divide?
• Is the cell big enough?
• Are there enough energy and other reserves?
• Is the DNA damaged?
G1 checkpoint

Telomeres



Telomeres

- A region of repetitive nucleotide sequences
- At the end of a chromatid

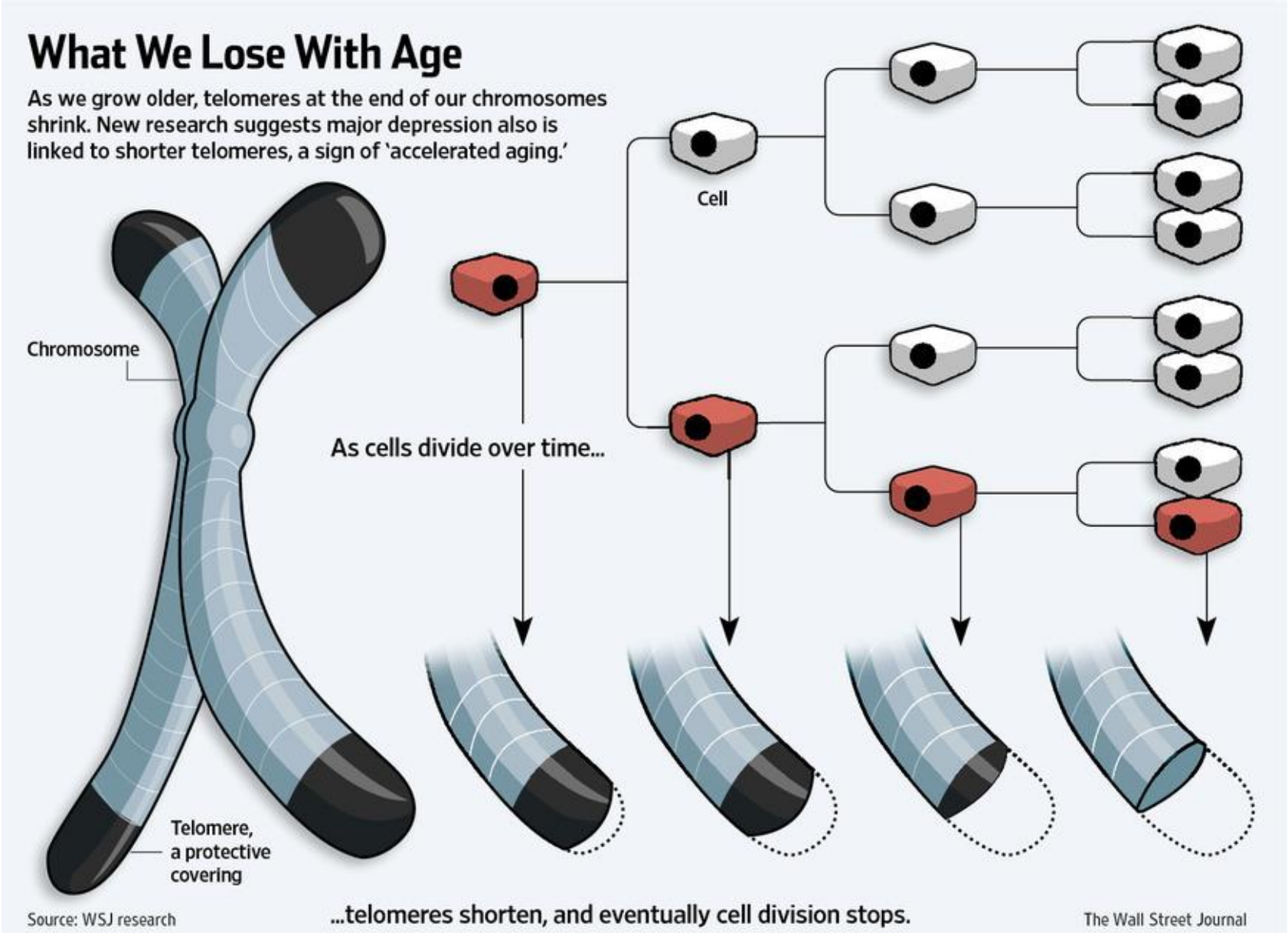
Role:

- DNA replicating enzymes stops a little before the end of DNA molecules
- Telomeres **prevent loss of genes** at the tips of each chromatid

BUT….

- **Telomeres get shorter** with each mitotic division
- So after many rounds of mitosis, aged cells eventually lose vital genes and die
- When cells age….we age too!

Telomeres


What We Lose With Age
As we grow older, telomeres at the end of our chromosomes shrink. New research suggests major depression also is linked to shorter telomeres, a sign of 'accelerated aging.'
Cell
Chromosome
As cells divide over time...
Telomere, a protective covering
Source: WSJ research
...telomeres shorten, and eventually cell division stops.
The Wall Street Journal

Updated on 13/7/21 by Beh SJ @behlogy

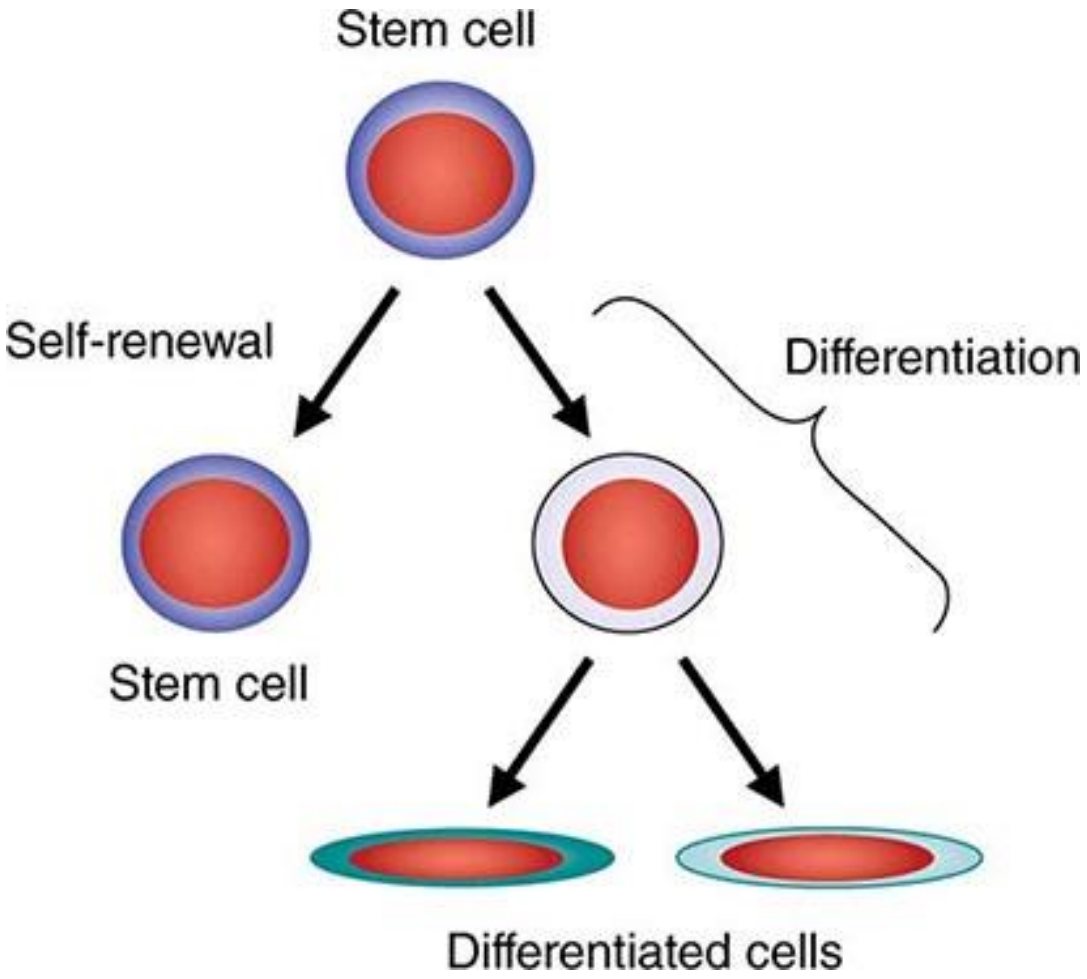
If only we can repair telomeres….

- The enzyme **telomerase** repairs telomeres
- It stops the telomeres from getting shorter each time a chromosome is replicated

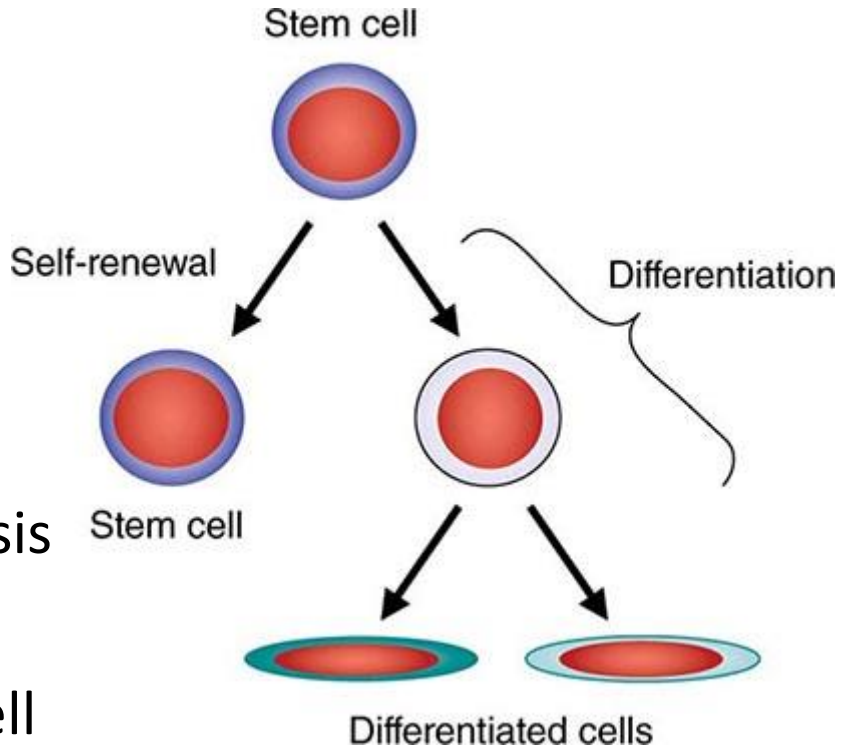
- But telomerase is NOT normally active in human body cells!

- It is however active in **stem cells**.
- As well as in **cancer cells** :O

Stem Cells


Stem cell
Self-renewal
Differentiation
Stem cell
Differentiated cells

Stem Cells



Features:

- Stem cells are **undifferentiated**

- Able to **continually divide** via mitosis

→ Bcs stem cells have **telomerase**

→ Telomeres do not shorten each cell cycle

- When it divides, it can produce:

→ A stem cell that divides

→ A cell that differentiates / specializes

- Many genes not switched off

Stem Cells

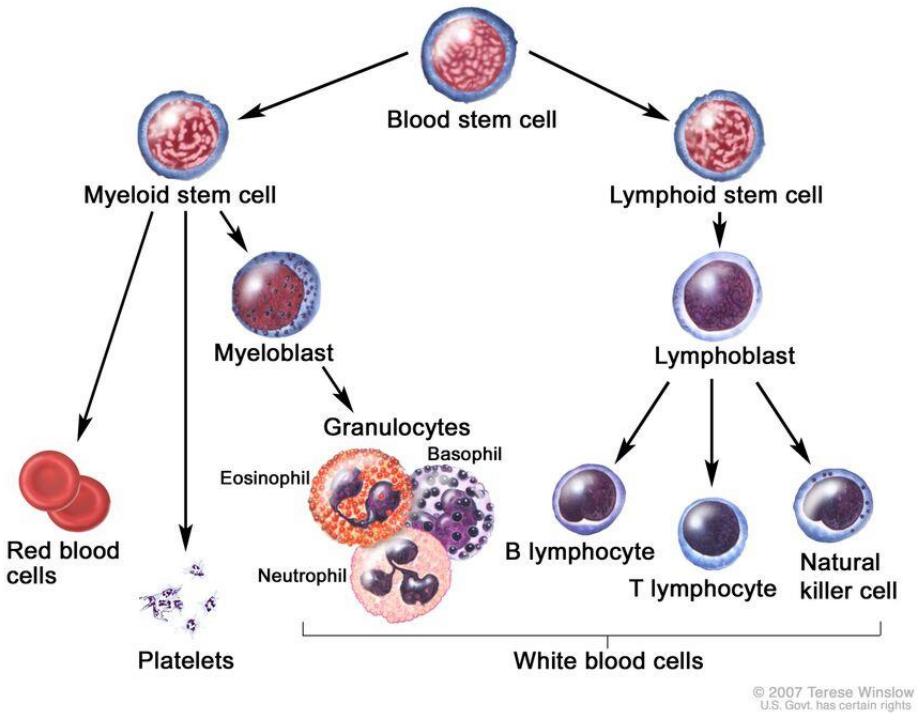
Roles:

- Form cells that can differentiate
- Divides to give continuous supply of stem cells
- For:

→ **Cell replacement**

→ **Tissue repair**

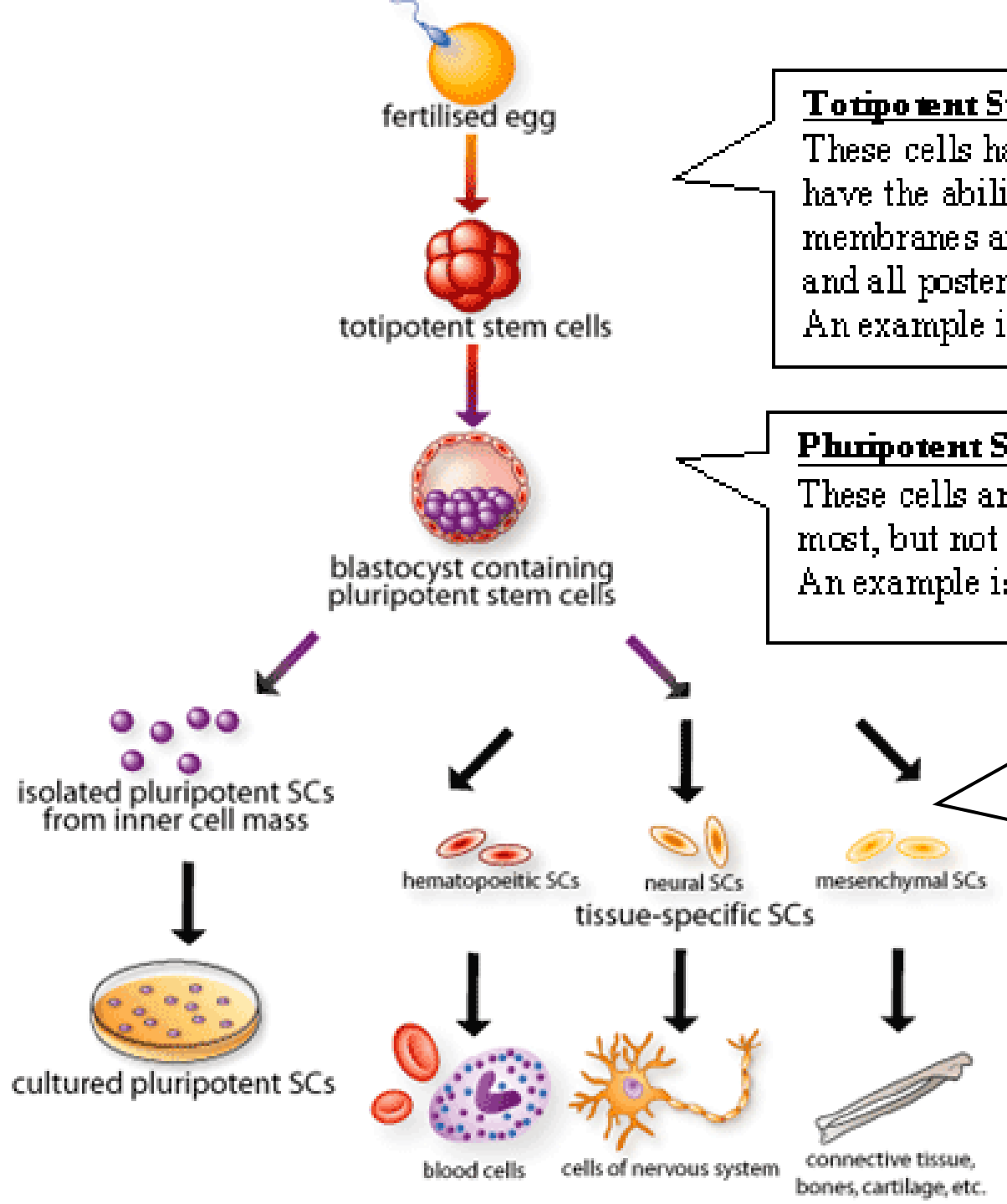
→ **Growth**



"Levels" of stem cells potency:

- **Totipotent**
- **Pluripotent**
- **Multipotent**

P/S: No need to memorise names of stem cells!



Totipotent Stem Cell

These cells have unlimited capability, and have the ability to form extraembryonic membranes and tissues, the embryo itself, and all postembryonic tissues and organs. An example is an embryo

Pluripotent Stem Cell

These cells are capable of giving rise to most, but not all, tissues of an organism. An example is inner mass cells

Multipotent Stem Cell

These cells are committed to give rise to cells that have a specific function. An example is blood stem cells

P/S: No need to memorise names of stem cells!

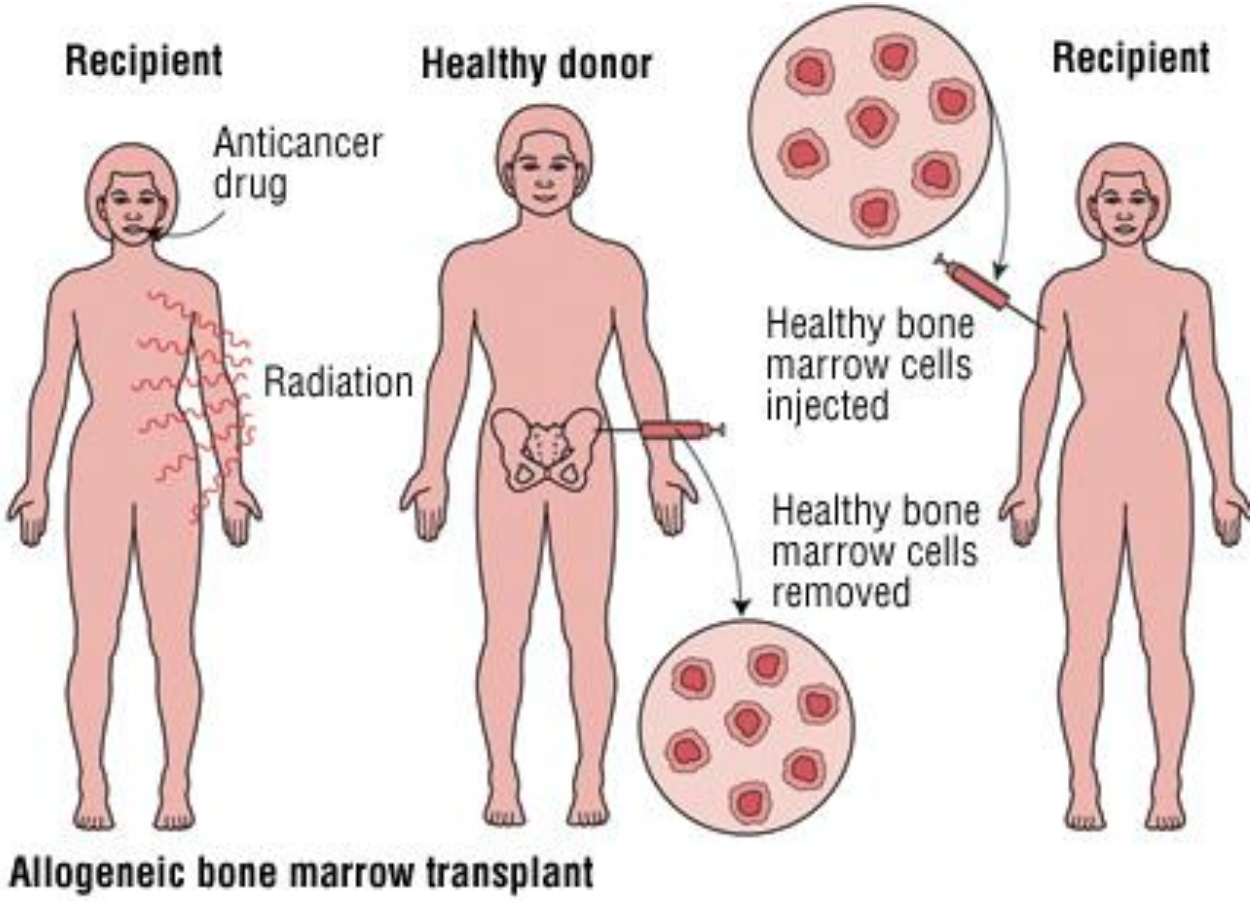
Updated on 13/7/21 by Beh SJ @behlogy

Stem Cells

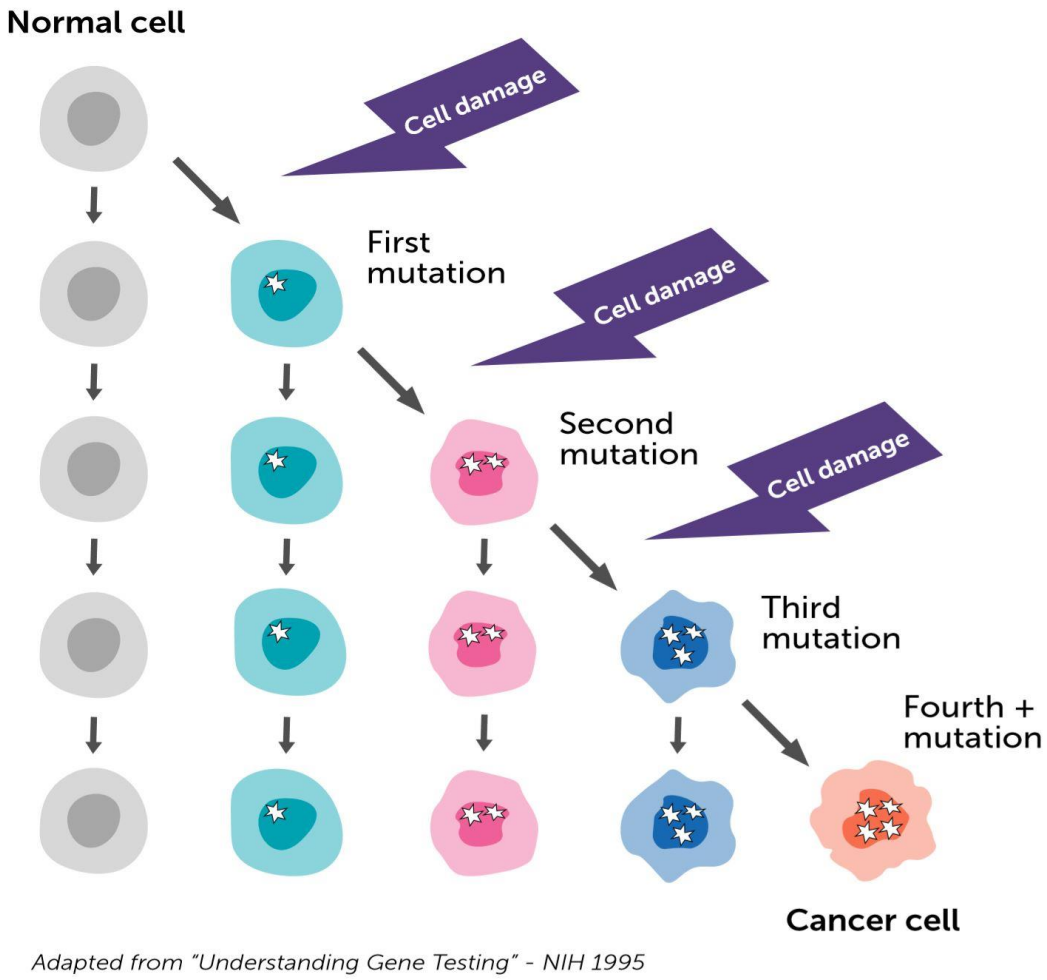
- **Stem cell therapy**

- Introduce new adult stem cells

- Promote healing of injury/disease



Cancer Cells



Adapted from "Understanding Gene Testing" - NIH 1995

Cancer

- Most common disease in developed countries
- 1 in 4 deaths

Most common cancers:

- Prostate cancer – men
- Breast cancer – women

- Shows us the importance of controlling cell division precisely

Cancer

- Result of **uncontrolled mitosis**

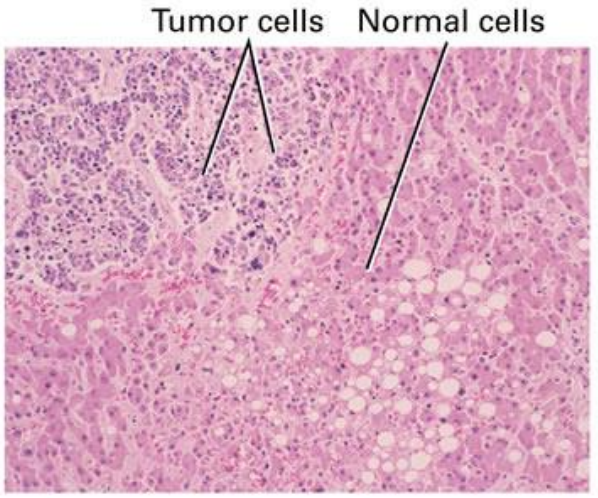
→Cells divide repeatedly

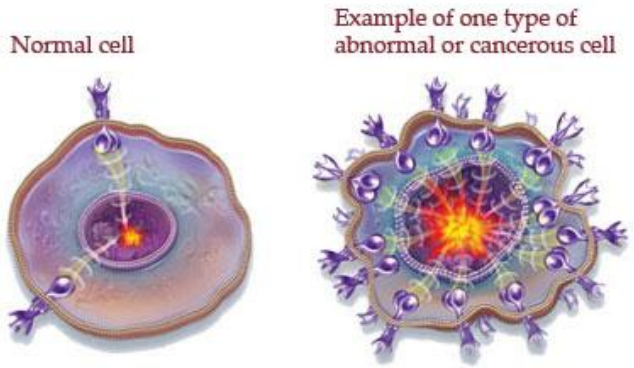
→Cell cycle checkpoints not controlled

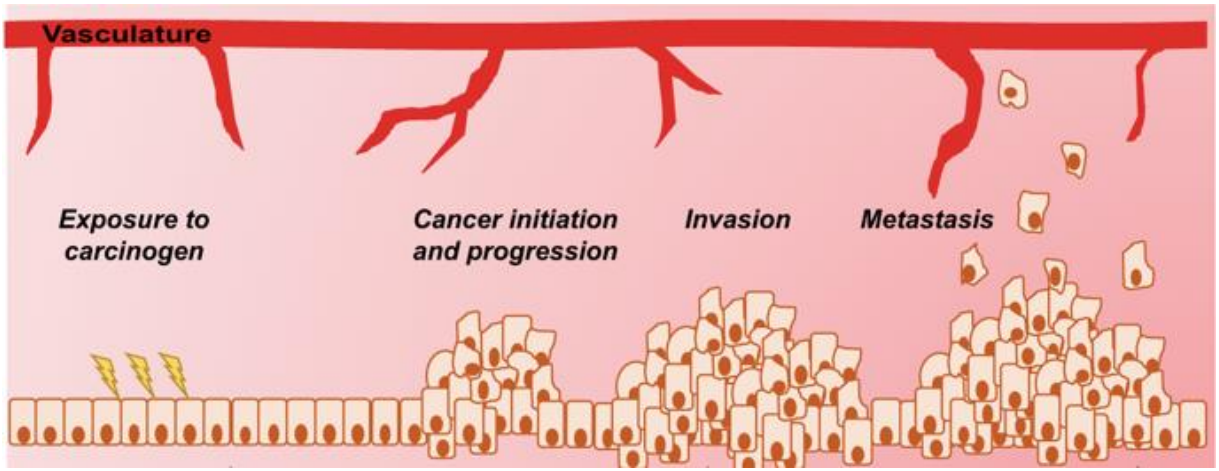
- **Short interphase**

→ DNA replication is error-prone

→ Very little growth







Factors Which Increases Risk of Cancer

- **Mutagen** = substance that causes mutation
- **Carcinogen** = Cancer-causing substance
- Not all / only some mutagens are carcinogenic
- Cancer is usually not due to a single mutation in a cell

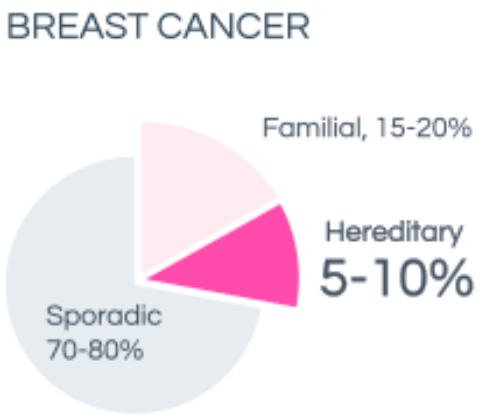
- **Mutagens:**

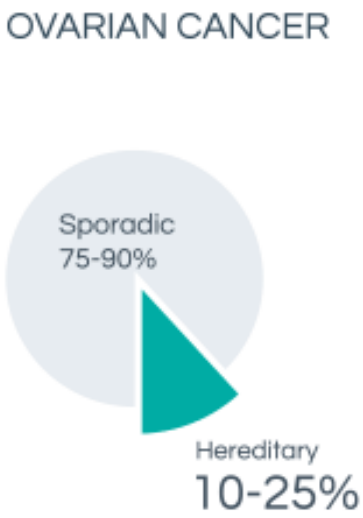
1) Ionising radiation (e.g. X-rays, gamma rays)
2) UV light
3) Free radicals
4) Chemicals (e.g. tar, ethidium bromide, mustard gas)
5) Virus infection (e.g. HPV, HIV)

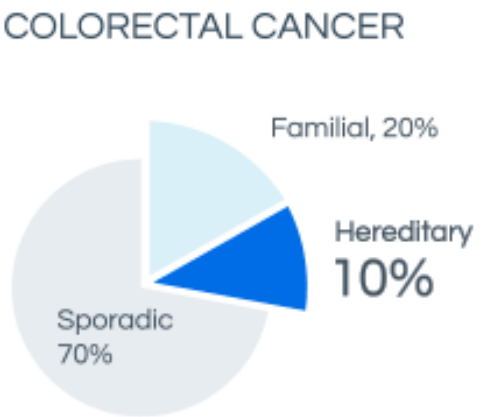
Factors Which Increases Risk of Cancer

Other factors that increase chances of cancer:

- Hereditary predisposition
- Tobacco smoking
- Obesity







What Causes Cancers?

- **Mutation** in genes that controls cell division

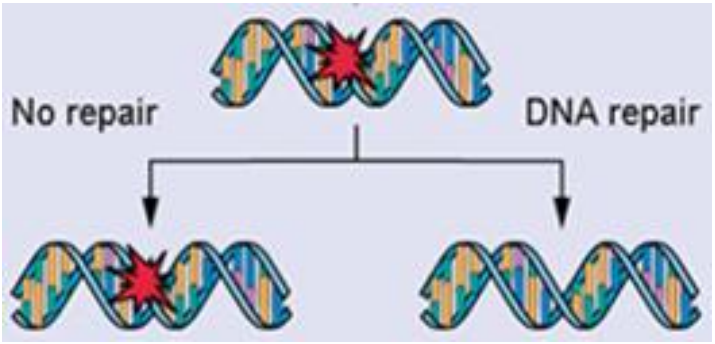
→ **Oncogenes** (mutated gene that causes cancer) is **switched on**

→ Proto-oncogene (normal gene) converted to an oncogene

→ **Tumour suppressor genes switched off**

- Cancer cells pass on mutations and oncogenes to daughter cells
- Cancer cells can **escape DNA repair** during interphase as well

→ result in **accumulated mutations**



What Causes Cancers?

Accumulated mutations in cancer cells can cause:

- **Immune system does not recognize** the cells as foreign and destroy it → avoid detection of immune system
- **No programmed cell death**

- Has **telomerase** → Can **divide indefinitely**
- Do not respond to extra/intracellular signals to stop dividing
- Mitosis is no longer inhibited by cell to cell contact → **no contact inhibition**

- Loss of function / cell specialization
- Form mass of undifferentiated cells = **tumour**

Tumour Development

1) **Carcinogens cause mutations** in gene which controls cell division
   → oncogene switched on

2) Cancerous cell **escape cell death and immune system**

3) Cell undergoes rapid and **uncontrolled mitosis**
   → grows into mass of unspecialised cells = **tumour**

4) Tumour grows, then **displaces and compresses** surrounding tissues

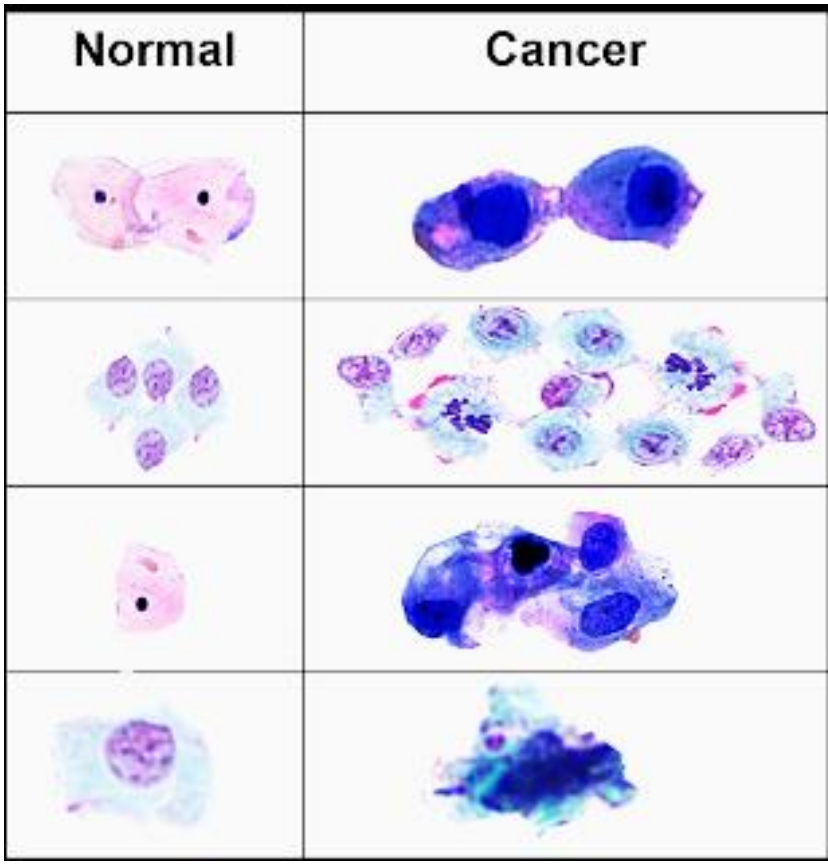
5) Growth of **blood capillaries** into tumour (angiogenesis)

Tumours

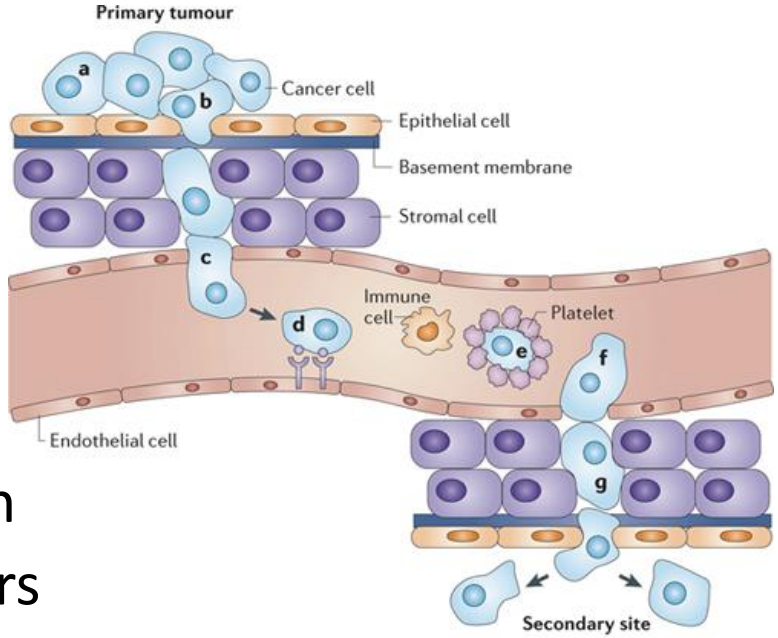
- **Mass of undifferentiated cells**
- No specific functions
- Result of uncontrolled cell division

- Has abnormal changes in cell shape
- Can grow, then **displace and compress** surrounding tissues

- Has **high demand of nutrients**
- As tumour grows, there can be growth of blood capillaries into tumour
- To deliver nutrients



Types of Tumours



a) Benign

- **Do not spread** from their site of origin
- E.g. warts, ovarian cysts, brain tumours

b) Malignant

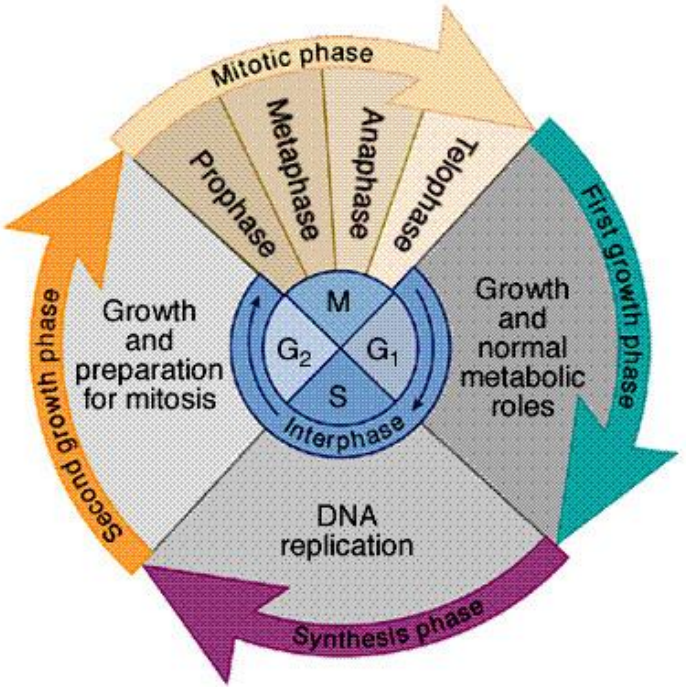
- **Can spread** throughout the body (**metastasise**)
- Can undergo **metastasis**

→Through blood and lymphatic system

→Invade and destroys other tissues in other areas

→Can result in **secondary growth**

Chapter Outline



Part 1: Cell Division

- Structure of chromosomes
- Importance of mitosis
- Interphase
- **Mitosis**
- Cytokinesis

Part 2: Regulation of the Cell Cycle

- Importance of **telomeres**
- **Stem cells** in cell replacement and tissue repair
- **Cancer and tumour** formation

Videos for fun...as usual

Mitosis: The Amazing Cell Process that Uses Division to Multiply!
https://www.youtube.com/watch?v=f-ldPgEfAHI

TED-Ed: How do cancer cells behave differently from healthy ones? - George Zaidan
https://www.youtube.com/watch?v=BmFEoCFDi-w

The Science of Aging
https://www.youtube.com/watch?v=BkcXbx5rSzw

WHAT CAN STEM CELLS DO?
https://www.youtube.com/watch?v=K7D6iA7bZG0